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PROVENANCES, DEPOSITIONAL RATES AND HEAVY METAL CHEMISTRY OF SEDIMENTS, PRINCE WILLIAM SOUND, SOUTHCENTRAL ALASKA

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PROVENANCES, DEPOSITIONAL RATES AND HEAVY METAL CHEMISTRY

OF SEDIMENTS, PRINCE WILLIAM SOUND, SOUTHCENTRAL ALASKA

A

THESIS

Presented to the Faculty of the University of Alaska

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

Larry Hal Klein, B.S.

Fairbanks, Alaska

September 1983

PROVENANCES, DEPOSITIONAL RATES AND

HEAVY METAL CHEMISTRY OF SEDIMENTS,

PRINCE WILLIAM SOUND, SOUTHCENTRAL ALASKA

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ABSTRACT

Clay mineral assemblages in the bottom sediments of Prince William Sound are attributed to two sources. The central basin, characterized by smectite and 1 Md mica polytype, derives its fine-grained sediments predominantly from the Copper River. Along the northern margin of the Sound, the clay mineral suite is devoid of smectite and contains 2M mica polytype. Sediments in the latter region are derived from the adjacent hinterland.

Variations in the ^{210}Pb-based sedimentation rates were identified. A general increase in the rates from Hinchinbrook Entrance to the central Sound and a progressive increase from Port Valdez to the Valdez Arm were recognized.

Areas (e.g., the southwestern margin of the Sound) have been identified with anomalously high Mn, Zn, and Cu in sediments. These anomalies lie adjacent to mineralized areas onshore. It is suggested that geochemical analysis of sediments has a potential use in the exploration for ore bodies onshore in the Sound.

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INTRODUCTION

The coastal regime of the North American continent can be delineated into two principal coasts, the "trailing edge" (e.g., east and Gulf coasts) and the "leading edge" (e.g., west coast) coastlines (Inman and Nordstrom, 1971). There are a number of embayed areas indented into the west coast. Most of the sedimentological research along this coast was restricted to low-latitude areas. The exceptions to this generalization are the extensive studies conducted on the depositional regime of Cook Inlet (Sharma and Burrell, 1970; Gatto, 1976; Hein et al., 1979), Glacier Bay (Hoskin and Burrell, 1972; Hoskin et al., 1974) and the fjords of British Columbia (Murray et al., 1978).

Prince William Sound is one of the few large embayed areas along the northern high-latitude subductive coast for which very little information is available on the processes and products of Holocene sedimentation. Some basic data on grain size distributions and chemistry of sediments from Prince William Sound and Port Valdez were gathered by Sharma (1974, 1979). Subsequently, Burbank (1974) mapped the suspended sediment plumes in the area. A detailed survey of the subsurface strata in Prince William Sound was accomplished by von Huene et al. (1967) using seismic profiling. Results of oil stranding experiments pertaining to sediments in intertidal areas were documented in a number of publications (Naidu, 1976; Feder et al., 1976; Norrell and Johnston, 1976; Shaw et al., 1977). More recently, Gosink and Naidu (in Shaw et al., 1983) were concerned with monitoring heavy metal pollution in Port Valdez, as related to the activities of the marine terminus of the trans-Alaska pipeline. Results of additional environmental studies for Port Valdez were summarized in Hood et al. (1973) and Colonell (1979).

From the foregoing review of the literature, it is obvious that serious data gaps exist which have limited our understanding of sediment dynamics in Prince William Sound. The specific purpose of this dissertation is to address certain aspects of the processes and products of sedimentation which may aid in bridging the above gaps.

The objectives of this study are to determine: (1) the sources and depositional sites of fine-grained sediments in Prince William Sound by using clay mineral assemblages in the surficial bottom sediments as a natural tracer, (2) the rates of sediment accumulation by means of a stratigraphic study of ^{210}Pb, and (3) the possibility of using geochemical anomalies of marine sediments in the search of heavy metal ore bodies in the onshore areas marginal to Prince William Sound.

GEOGRAPHIC AND GEOLOGIC SETTINGS

Prince William Sound, an embayment of the northern Gulf of Alaska, is a topographically rugged region and is bordered to the north, east and west by the orogenic belt of the Coastal range. The Sound is bounded by 59°55' and 60°58' N latitudes and 145°30' and 148°45' W longitudes (Figure 1), and covers an area of 3,595 km^2. This re-entrant has its shoreline indented by numerous glacial fjords, bays and inlets. The depth in the Sound varies from a maximum of 870 m in the western region to a 300-400 m deep north-south trending trough situated between the Valdez Arm and Hinchinbrook Entrance.

The Kenai-Chugach Mountains, surrounding the northern half of Prince William Sound, reach elevations up to 4 km and are blanketed by permanent snowfields containing several major glaciers. South of Prince William Sound is the Gulf of Alaska, delineated from the Sound by Montague and Hinchinbrook islands.

This sub-arctic coastal embayment is characterized by a fjord-type estuarine system (Muench and Schmidt, 1975). The geomorphology of the region is a resultant of active glaciation and tectonism. The most recent major tectonic event affecting the area was the March 27, 1964, earthquake, whose epicenter was located along the Sound's northern margin.

Many of the rivers entering the Sound are small and arise from precipitous drainage areas not exceeding 260 km^2 (Wahrhaftig, 1965).

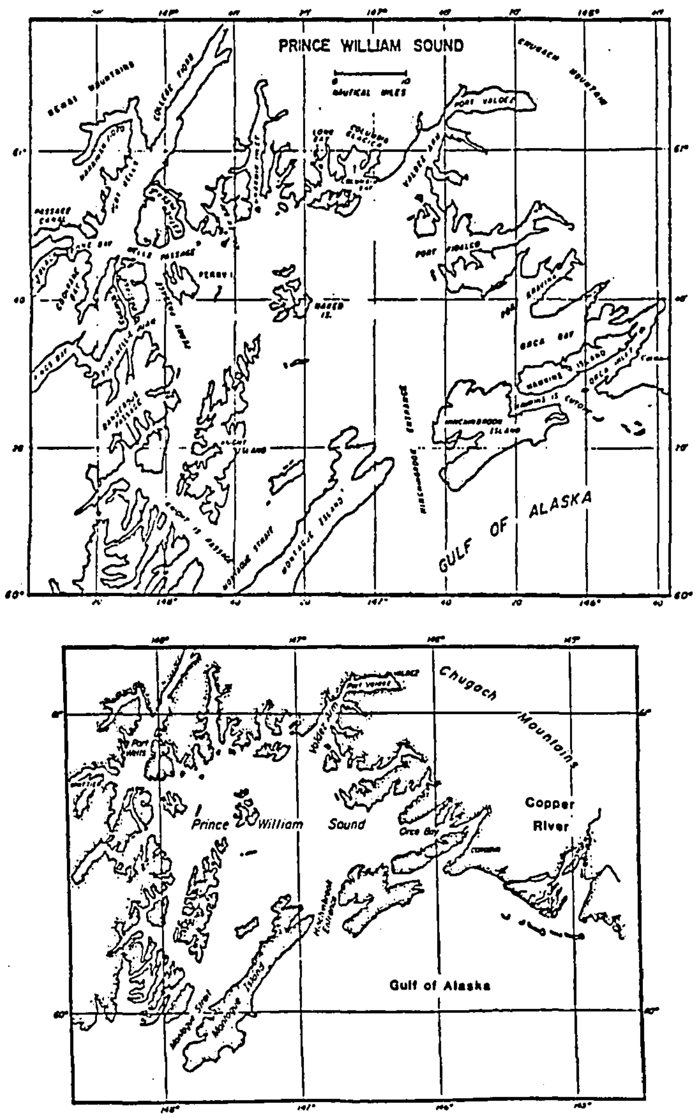

Figure 1. Study area.

The Copper River, east of the Sound (Figure 1), supplies large amounts of sediment to the Sound through Hinchinbrook Entrance and Hawkins Island Cutoff via the Alaska Coastal Current (Royer et al., 1979).

Mean monthly precipitation in the Sound ranges from 457 cm in the south to 157 cm in the northern region. Mean air temperatures range from -5°C (15°F) in winter to 14°C (55°F) in summer, with a mean annual temperature of 5°C (42°F) (Muench and Schmidt, 1975). The minimum surface water temperature during the winter is <2°C with a summer maxima of about 12°C. The surface salinity during the winter is approximately $32^{o}/oo$ while the minimum during the summer as a result of higher freshwater runoff is $15^{o}/oo$ (Muench and Schmidt, 1975). Prince William Sound constitutes the northern-most marine region free from seasonal ice cover. Thin sea ice and small ice floes, however, occur adjacent to the major glaciers in winter.

A geological survey of the Prince William Sound region has revealed that the oldest formations are of Jura-Cretaceous age. These rocks are composed of two groups--the Valdez Group, exposed in the northern and western hinterland of the Sound; and the Orca Group, exposed east of the Sound and on the islands along the southern margin (Plafker, 1969). Both the Valdez and Orca Groups are complexly folded and faulted.

The Valdez Group is of Jurassic to Cretaceous age. This sequence is composed of metamorphosed marine graywacke, argillite and slate with interbedded conglomerates. Overlying the Valdez Group are the Orca Group of early Tertiary (Paleocene to Eocene) age, which consists of volcanogenic and interbedded sedimentary and metasedimentary rocks (Moffit, 1954). The sedimentaries are primarily sandstones, siltstones, shales, graywackes and slates, whereas the volcanics consist mostly of pillow basalts. The regolith in this high latitude region is a resultant of physical rather than intense chemical weathering.

The substrate of the Sound is predominantly composed of clay, with subordinate silt, minor amounts of sand and rare gravel (Burbank, 1974; Sharma, 1979). The high energy regions, occurring in the narrow passages of the Sound, contain gravelly sands with little silt.

In central Prince William Sound, three acoustic subsurface sedimentary units have been deduced (von Huene et al., 1967). The basal unit is comprised of the Orca and Valdez Groups which are successively overlain by late Pleistocene glacial and Holocene marine sediments.

MATERIALS AND METHODS

SAMPLING

A suite of approximately 150 Shipeck and/or van veen grab samples were collected on board the R/V Alpha Helix at closely spaced intervals along selected transects covering the Sound. Additionally, 30 grab samples collected in earlier cruises by Drs. Naidu and Sharma, were taken for analysis. In Figure 2 and Appendix A, the locations of the samples are indicated.

In order to elucidate the depositional processes, and estimate the sedimentation rates in the Sound, a number of Benthos gravity cores were retrieved at selected stations from Port Valdez to Hinchinbrook Entrance (Figure 3).

CLAY MINERAL ANALYSIS

To determine the sources of clay minerals in Prince William Sound, 104 surficial bottom sediment samples were taken for analysis. The procedure for clay mineral analyses (after Naidu and Mowatt, 1983) was as follows. Splits of sediment samples were placed in beakers and treated with H_2O_2 to remove organic material. The sample was then placed in a blender for approximately five minutes and the resulting slurry was sieved through a 230 mesh (62 μm) sieve. The <62 μm

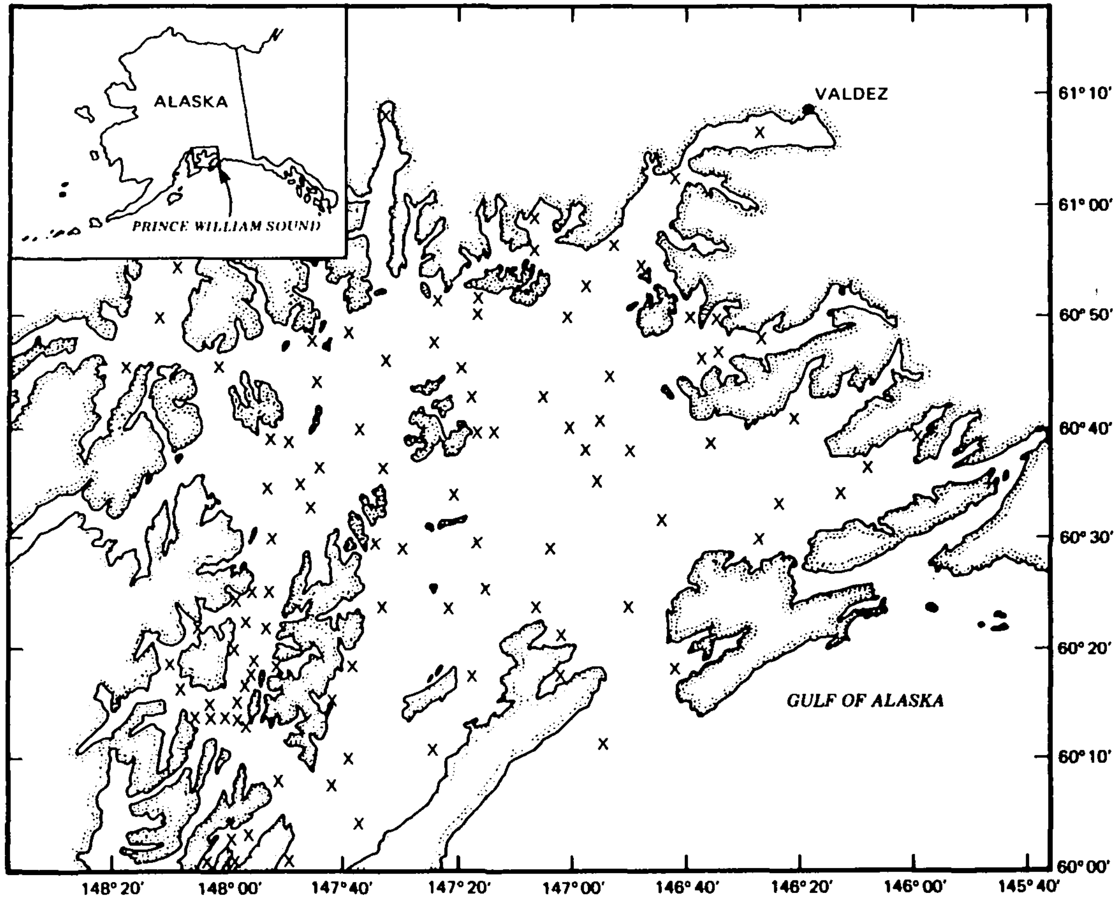

Figure 2. Map of Prince William Sound, showing locations of sediment samples analyzed.

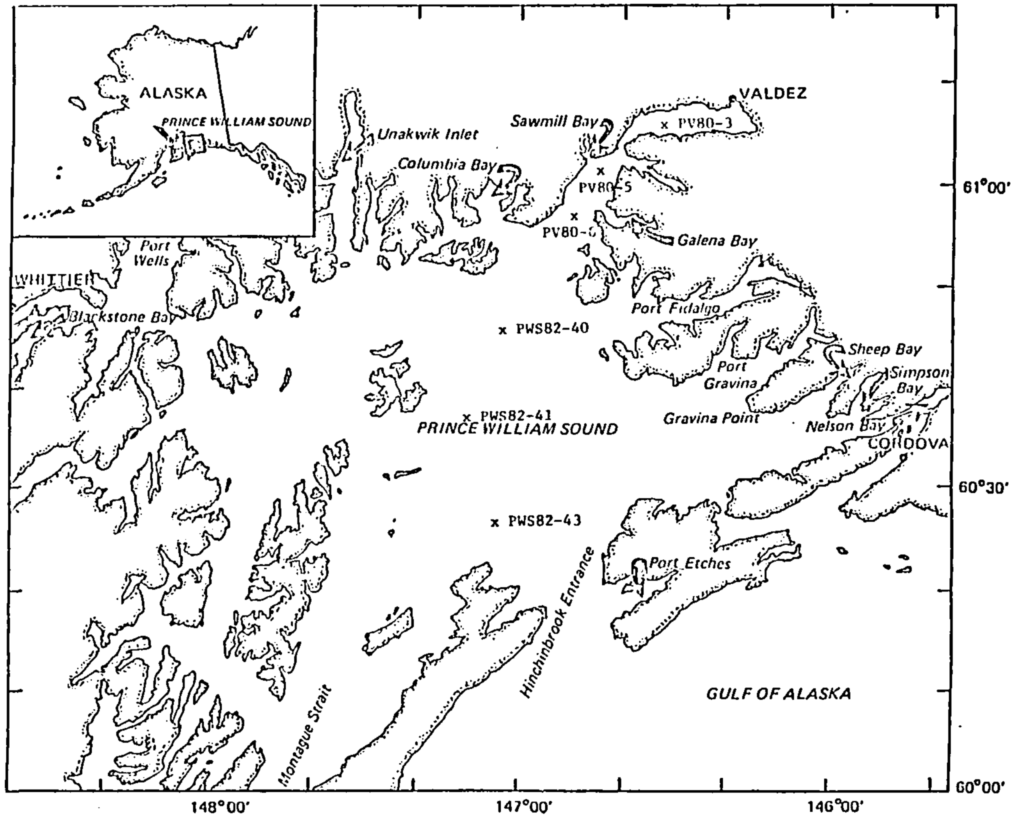

Figure 3. Locations of gravity cores used for ^{210}Pb geochronology and stratigraphy.

fraction was then taken into a 1000 ml settling tube. Repeated washings were done with distilled water until flocculation ceased and a stable suspension occurred. The <2 μm equivalent spherical diameter (e.s.d.) fraction which was separated from the suspension using Stoke's Law, was centrifuged and oriented on glass slides by the smear technique (Gibbs, 1965).

Upon drying, the slides were placed in a desiccator and exposed to ethylene glycol vapor for 48 hours. The glycolated samples were then examined on a Rigaku Geigerflex X-ray diffractometer using Cu Kα Ni-filtered radiation at 30 kv and 30 ma. For each of the samples, a fast scan (2° 2θ/min.) extending from 2° to 35° 2θ, as well as a slow scan (¼° 2θ/min.) covering from 24° to 26° 2θ was obtained (Carroll, 1970; Brindley and Brown, 1980). Kaolinite and chlorite were resolved on the basis of slow scans (Biscaye, 1964). The clay minerals, kaolinite, chlorite, illite and expandable phases (under the "Expandable Group" are included clay minerals which expand upon glycolation, and display a basal diffraction peak (001) of approximately 17 Å were identified by their characteristic basal reflection patterns (Brindley and Brown, 1980). Semiquantitative estimations of clay minerals were accomplished by the method outlined by Biscaye (1965).

In order to further differentiate the clay mineral assemblages, mica polytypes were obtained. Discerning whether mica polytypes occurring in the bottom sediments of Prince William Sound are 2M (two-layer Monoclinic), 1M (one-layer Monoclinic) or 1 Md (one-layer

Monoclinic disordered) aid in identifying if illite is authigenic (1M and 1 Md) or detrital (2M) in origin (Weaver, 1967).

To resolve the illite polytypes, a split of the <2 μm fraction slurry from the suspension as described earlier, was allowed to air dry in a beaker. The dried clays were then finely powdered and mounted in an aluminum holder to provide randomly oriented particles. The resultant fine-grained powder was subjected to X-ray diffraction analysis and run on a fast scan from 2° to 63° 2θ. The polytypes were identified according to the criteria presented by Yoder and Eugster (1955).

The term "Illite" in this thesis is used in the sense of Brindley (1980). Ratios of the illite 10 Å/5 Å peaks were calculated because it appears that the ratios of the peak height as well as those of the peak areas relative to the 10 Å/5 Å, respectively, are closely correlatable with the trioctahedral or dioctahedral nature of the illite family of clay minerals (Weaver, 1965).

^{210}Pb ANALYSIS

The application of ^{210}Pb stratigraphy in the estimation of sedimentation rates was first recognized by Goldberg (1963). Additionally, variations of ^{210}Pb profiles along core lengths have been useful in understanding the depositional history of a basin (UNESCO, 1978).

^{210}Pb chronological studies have been used to estimate rates of sedimentation and to elucidate sedimentary processes in lakes (Krishnaswami et al., 1971; Robbins and Edgington, 1975), estuaries (Thompson et al., 1975; Goldberg et al., 1977), fjords (Bruland, 1974) and coastal marine sediments (Koide et al., 1972, 1973; Bruland, 1974).

To estimate sediment accumulation rates in Prince William Sound, ^{210}Pb geochronology was employed. ^{210}Pb (half life 22.3 years), which is a member of the ^{238}U radioactive decay series, is incorporated into the sedimentary cycle by the following events. ^{222}Rn (half life 3.8 days), a noble gas nuclide, is emanated from regolith to the atmosphere from its ^{226}Ra precursor (half life 1,622 years). ^{222}Rn decays in the atmosphere to produce a sequence of extremely short-lived radionuclides which subsequently decay to produce ^{210}Pb. Due to the relatively short half-lives of the intermediate decay products compared to the atmospheric aerosols, practically all the ^{222}Rn atoms are converted to ^{210}Pb. ^{210}Pb is returned to the earth via precipitation and dry fallout. Once entering the surface ocean, ^{210}Pb is quite rapidly removed from seawater by the sediments, thus having a short residence time in the ocean and even shorter time (less than one year) in coastal waters (Bruland, 1974). Since ^{210}Pb has a 22.3 year half-life, the application of the ^{210}Pb method to examine recent sedimentary processes is generally applicable over five half-lives or approximately 100 years.

The samples were analyzed for ^{210}Pb by following the methods described by Koide et al. (1973) and Nittrouer et al. (1979).

Centimeter splits of gravity cores were placed into pre-weighed whirlpack bags and weighed, and wet weights of the samples were then derived. The samples were then frozen overnight and freeze dried at -65°C (-85°F) for approximately 48 hours. The loss in weight upon drying provided the water content in the sediments. The freeze drying was preferred over oven drying to minimize loss of ^{210}Pb from the sample.

Secular equilibrium between ^{210}Pb and its daughter, ^{210}Po, was assumed. Two grams of dried sediment sample were placed in a beaker into which 100 ml of 6N HCL was added (Kipphut, 1978). Two ml of ^{208}Po (activity at t_o = 9.5302 dpm/ml) was then added as a tracer. The beaker was placed on a hot plate at 80°C for one and one-half hours, and then allowed to cool.

The slurry was centrifuged and the supernatant liquid was drawn off into a beaker and evaporated until approximately 20 ml remained. This residual solution was brought up to a 100 ml volume with distilled water. Ascorbic acid was then added in order to form a complex with Fe^{+3} which interferes with the plating of polonium onto a silver disc (Flynn, 1968). The beaker, with the addition of a silver disc, was placed on a hot plate at 80°C for one and one-half hours at which time the silver disc was removed, and alpha activities of ^{210}Po and ^{208}Po were measured using a NS-700 pulse height analyzer (see Appendix B).

Accumulation rates (cm/yr.) were obtained from the best-fit line of the plots of log excess ^{210}Pb versus core depth. To remove inaccuracy in the sedimentation rates as a result of compaction, mass sedimentation rates ($g/cm^2/yr.$) were computed [density of sample multiplied by the sedimentation rate (cm/yr.)].

HEAVY METAL ANALYSIS

The specific purpose of the geochemical analysis of Prince William Sound sediments was to identify heavy metal anomalies, which could be put to use in the exploration of ore bodies in the onshore area adjacent to the Sound.

Preparation of the sediment for the determination of the concentrations of a suite of heavy metals (Zn, Co, Ni, Cu, Cr, Pb, V, Mn, Fe) in the gross sediments of Prince William Sound was accomplished using the method described by Rader and Grimaldi (1961). The sediment samples were first oven-dried at 110°C and then finely powdered using an agate mortar and pestle. A 0.5 gram powdered sample was placed in a platinum crucible and gradually heated to drive off the water of hydration. The sample was then ashed over a burner and allowed to cool. It was then moistened with a few drops of distilled water, and a 20 ml aliquot each of concentrated HNO_3 and 40% HF was added. Subsequently, the sample was digested on a hot plate and eventually evaporated to dryness. To the dry residue, 20 ml of concentrated HNO_3 was added and evaporation to dryness repeated. The resulting residue was first dissolved, and then made up to 25 ml using 10% HNO_3. The 25 ml solutions were transferred into plastic polyseal bottles.

In recent years it has been generally accepted that geochemical anomalies can usually be enhanced by the use of partial dissolution techniques on soils and sediments. For the purpose of anomaly enhancement, metal analysis was usually performed on oxalic acid extracts of geological samples. More recently, Filipek et al. (1982) suggested that leaching of samples with hydroxylamine hydrochloride is probably a more effective procedure to augment geochemical anomalies. This study has basically followed Filipek and others' (1982) recommendations but with slight modification. To the hydroxylamine hydrochloride, an aliquot of 25% acetic acid was added (Chester and Hughes, 1967), and this reagent complex (HHA) was then used to extract metal leachates from about 50 gross powders of marine sediment samples from Prince William Sound.

The metal analyses were performed on a Perkin Elmer, Model 603, and Model 5000 atomic absorption spectrophotometer units with HGA 500 graphite furnace. It should be noted that the concentrations of metals in the extractable fraction of Prince William Sound sediments were resolved predominantly for two coastal regions (Chenega-Knight Island area and Port Valdez). The central Sound was excluded because the sole purpose of acquiring the chemical partitioning patterns for geochemical anomalies was to determine sites of onshore mineralization.

Correlation coefficient analysis between the various metals, grain size parameters and clay minerals pertaining to sediments of the Chenega-Knight Island area was accomplished to establish interelement and textural-element-clay mineral correlations.

ACCURACY AND PRECISION OF ANALYSES

Sources of some degree of error are inherent in any scientific study. For this particular work involving clay mineralogy, limitations on the data are due to the semi-quantitative estimations of clay minerals (Johns, Grim and Bradley, 1954; Biscaye, 1965; Pierce and Seigel, 1969). The precision of the clay mineral analysis on oriented samples was ±5%; whereas the precision for unoriented clays was better than 1%.

The alpha counting relating to the ^{210}Pb analysis (by using its daughter ^{210}Po and measuring alpha emissions) showed a statistical error of 3%. The analytical precision for the heavy metal chemical analyses were: Zn, 6%; Co, 7%; Ni, 5%; Cu, 9%; Cr, 5%; Pb, 5%; V, 4%; Mn, 2%; Fe, 3%. The analytical accuracy was obtained by chemically analyzing U.S.G.S. Standard rock powders and comparing data with those published by Flanagan (1969, 1973), as shown in Table 1.

Table 1. Average concentrations of some heavy metals in standard U.S. Geological Survey rocks: AGV-1, BCR-1, and G-2.[1]

U.S.G.S. Standard Sample	V	Cr	Mn	Fe	Co	Ni	Cu	Zn
AGV-1								
This study--1	--	9.6	--	4.67	15.0	13.0	59.2	99
This study--2	127	12.8	767	4.79	14.6	14.5	--	--
Reported literature values:								
Flanagan, 1969	121	12.9	728	4.76	15.5	17.8	63.7	112
Flanagan, 1973	125	12.2	763	4.73	14.1	18.5	59.7	84
Range (Flanagan, 1969)	79-171	8-45	640-870	4.26-5.21	10-30	11-27	52-83	64-304
BCR-1								
This study--1	--	10.7	--	--	33.7	5.9	17.5	136
This study--2	500	14.6	1,425	8.98-8.94	35.7	6.4	--	--
Reported literatures values:								
Flanagan, 1969	384	16.3	1,350	9.44	35.5	15.0	22.4	132
Flanagan, 1973	399	17.6	1,406	9.37	38.0	15.8	18.4	120
Range (Flanagan, 1969)	120-700	8-45	1,040-1,600	9.02-9.97	29-60	8-30	7-33	94-278
G-2								
This study--1	38	10.0	258	1.58	15.0	17.0	7.6	88
Reported literature values:								
Flanagan, 1969	37	9.0	265	1.93	4.9	6.4	10.7	74.9
Flanagan, 1973	35.4	7.0	260	1.85	5.5	5.1	11.7	85
Range (Flanagan, 1969)	26-60	5-29	180-360	1.53-2.44	2-21	2-14	<2-17	42-138

[1]Measurements in μg/g, except for Fe which is in $\mu g/g \times 10^4$.

RESULTS

CLAY MINERALS IN THE PRINCE WILLIAM SOUND AREA

Distribution

The locations of 104 sediment samples analyzed for clay mineral assemblages are shown in Figure 2 and the clay mineral concentrations corresponding to these samples are listed in Appendices C and D. Illite and chlorite are the predominant clay minerals in Prince William Sound and are monotonously uniform throughout the region. Smectite exists in trace amounts. A clear differentiation of kaolinite and chlorite for some of the samples was not possible from the analysis of the slow scans of the 3.5 Å diffraction peak. In cases where such a resolution was precluded, the amounts of kaolinite and chlorite were grouped together (Appendix C). The average composition (weighted peak area percent) of the clay mineral assemblages are: 56% illite, 42% kaolinite and chlorite, and 2% smectite. Invariably, the concentration of kaolinite was less than 6%.

The aerial distribution patterns of the weighted peak-area percentages for the various clay minerals are shown in Figures 4 through 6. Some broad trends in the clay mineral patterns are recognizable (Appendix D). The highest concentrations of smectite exist in southcentral Prince William Sound; a net decrease is observed both toward the east and west. Along

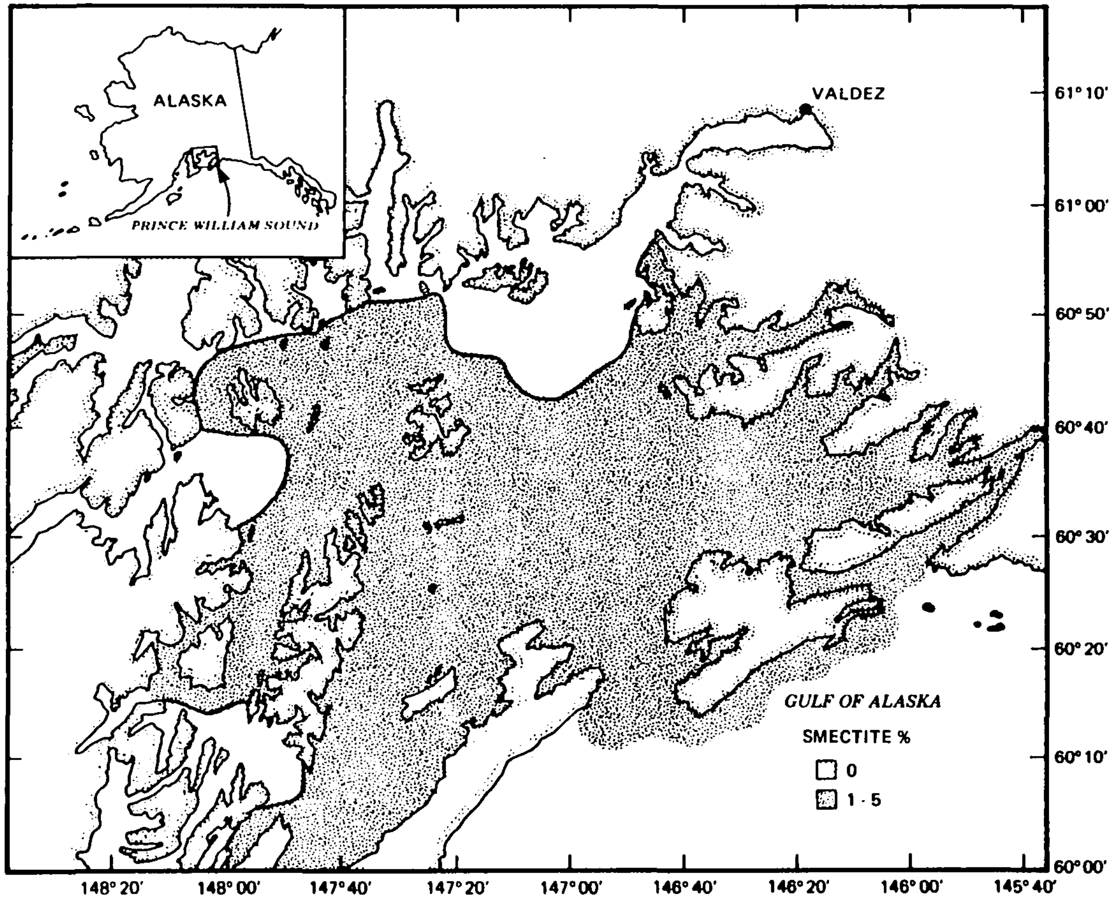

Figure 4. Distributional pattern of smectite in Prince William Sound.

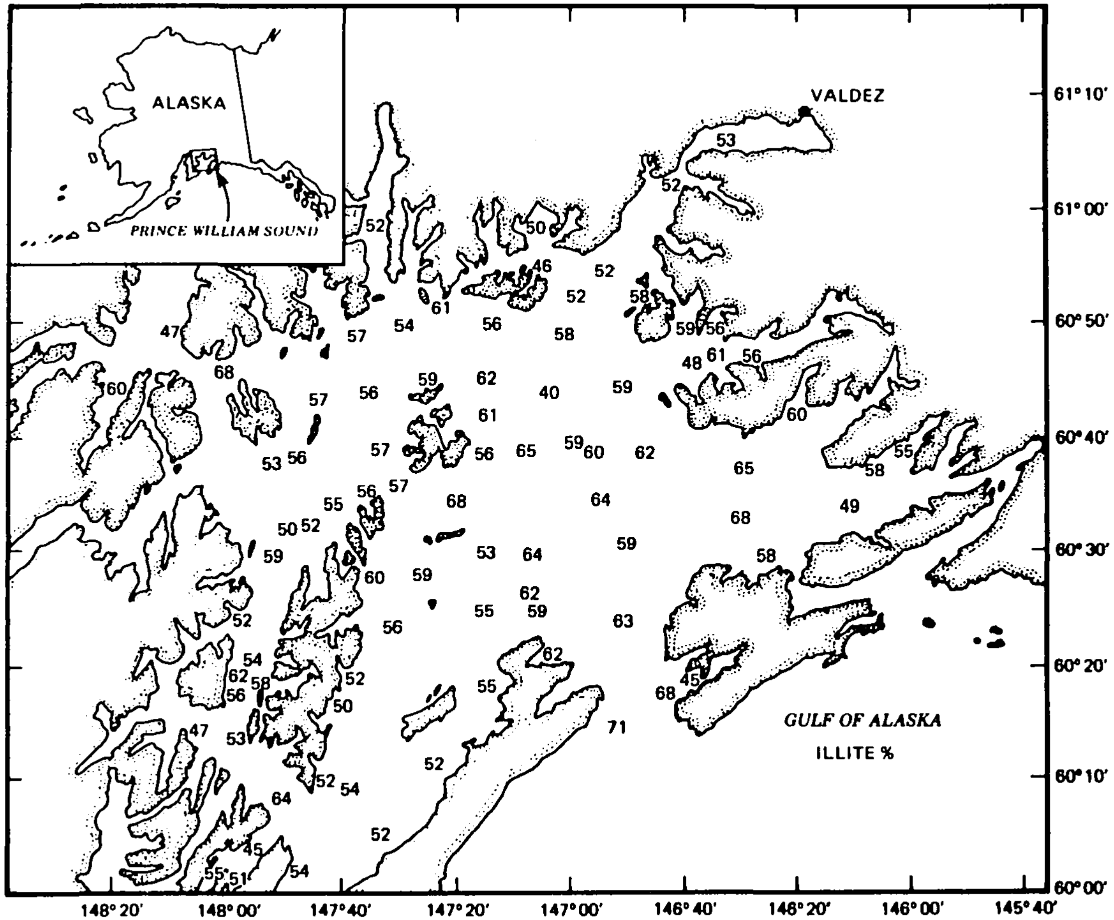

Figure 5. Distributional pattern of illite in Prince William Sound.

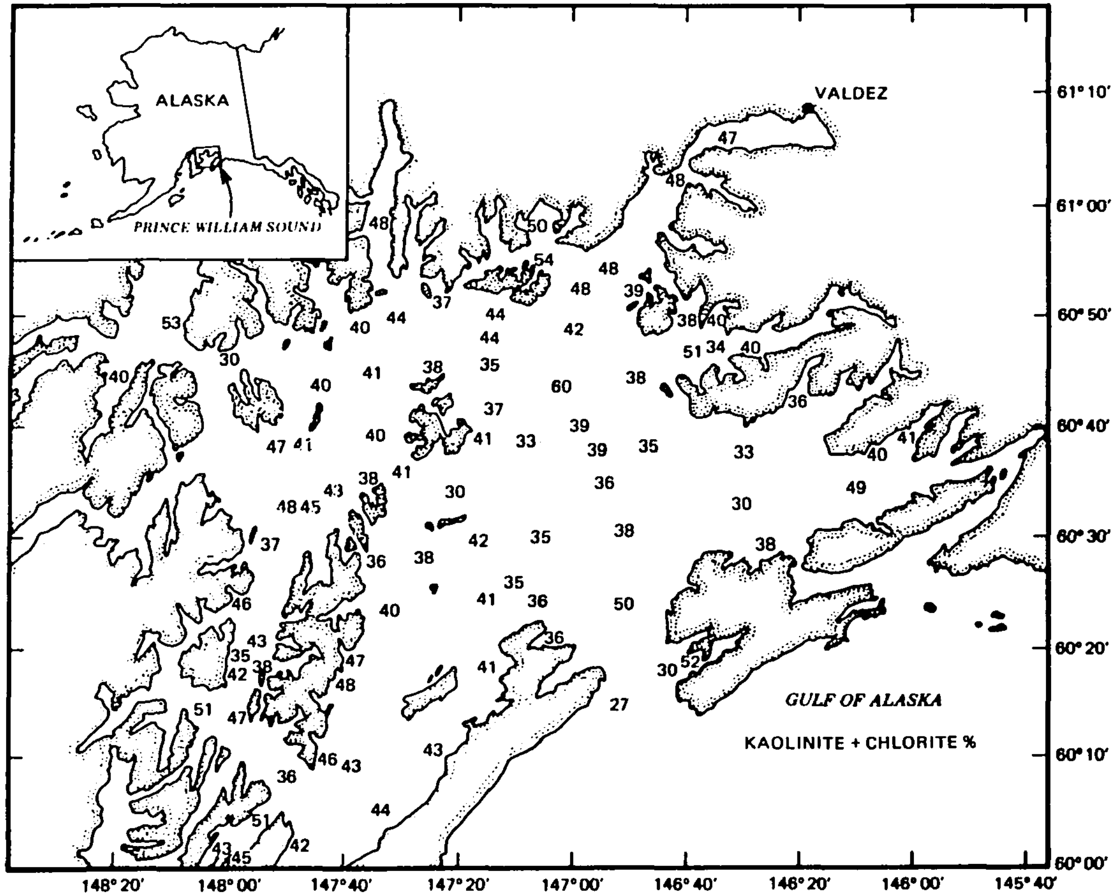

Figure 6. Distributional pattern of kaolinite and chlorite in Prince William Sound.

the northern and northwestern margins of the Sound, there is a notable absence of smectite. No definite trends, however, are perceivable for gross illite, kaolinite or chlorite.

Illite Polytypes

The distributional pattern of illite polytypes is shown in Figure 7 and listed in Table 2. The analysis of the illite polytypes reveals a markedly significant regional variation within Prince William Sound. The 2M illite polytype (as exemplified by the presence of 3.74 Å, 3.00 Å and 2.80 Å peaks in the X-ray diffraction trace) exists primarily in the sediments of the northern marginal region (Figure 7). In contrast, the 1Md illite polytype (as exemplified by the 3.66 Å peak in the X-ray diffraction trace) predominates throughout the remainder of the Sound (Appendix E).

Illite 10 Å/5 Å Ratios

Peak height and peak area ratios relative to the 10 Å/5 Å peaks are presented in Appendix F, and their regional distribution is illustrated in Figures 8 and 9, respectively. Figure 8 shows that the highest 10 Å/5 Å peak height ratios exist in the central and southcentral regions of Prince William Sound and that the ratio decreases significantly towards the coastline. A tongue of sediments with relatively low ratios, however, protrudes into the central Sound from the eastern boundary.

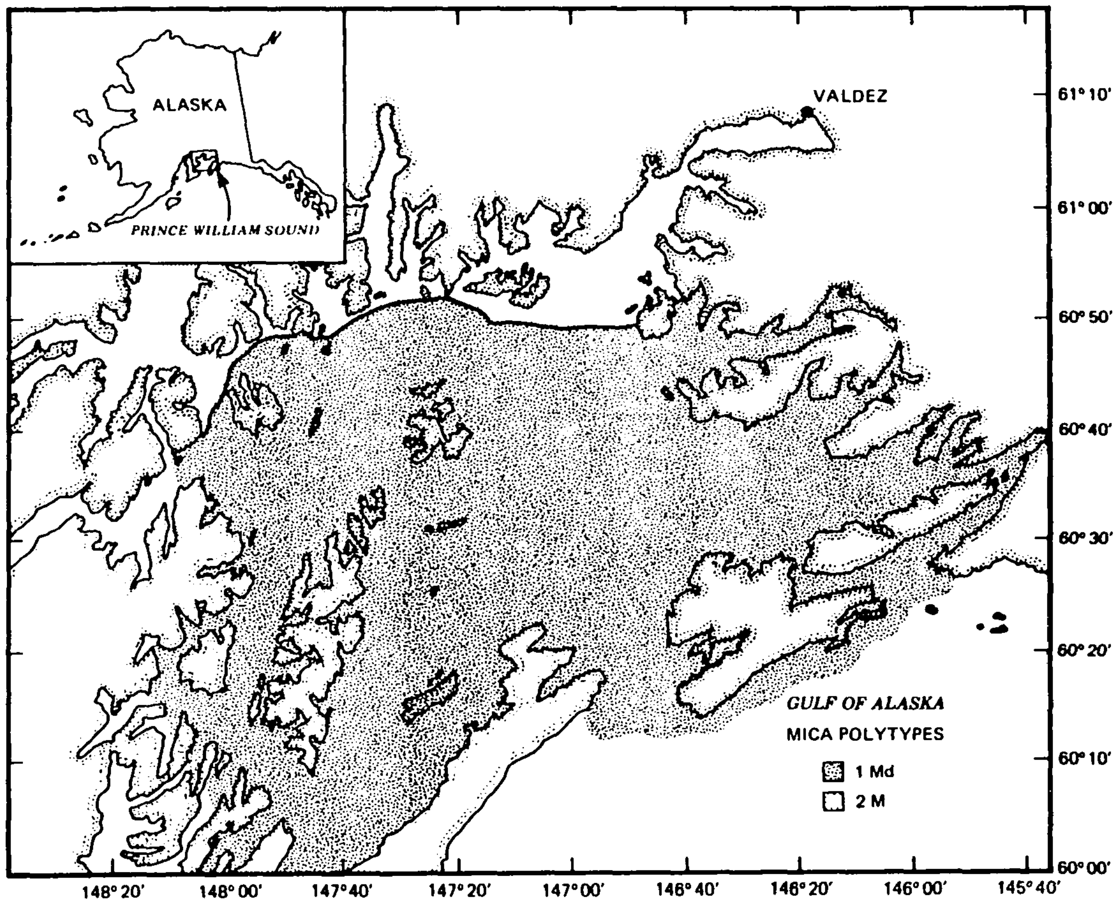

Figure 7. Distributional pattern of mica polytypes in Prince William Sound.

Table 2. Mica polytypes in the <2 μm size fraction of surficial bottom sediments from Prince William Sound.

Sample	Mica Polytype
PWS 66-3	1 Md
PWS 66-11	2 M
PWS 66-20	1 Md
PWS 66-21	1 Md
PWS 66-22	1 Md
PWS 66-23	1 Md
PWS 73-12	2 M
PWS 73-22	1 Md
PWS 73-23	1 Md
PWS 73-27	1 Md
PWS 73-28	1 Md
PWS 73-32	1 Md
PWS 79-3	1 Md
PWS 79-7	1 Md
PWS 79-30	1 Md
PWS 80-17	1 Md
PWS 80-19	1 Md
PWS 80-20	1 Md
PWS 81-2	1 Md
PWS 81-6	1 Md
PWS 81-7	1 Md
PV 50	2 M
PV 56	2 M

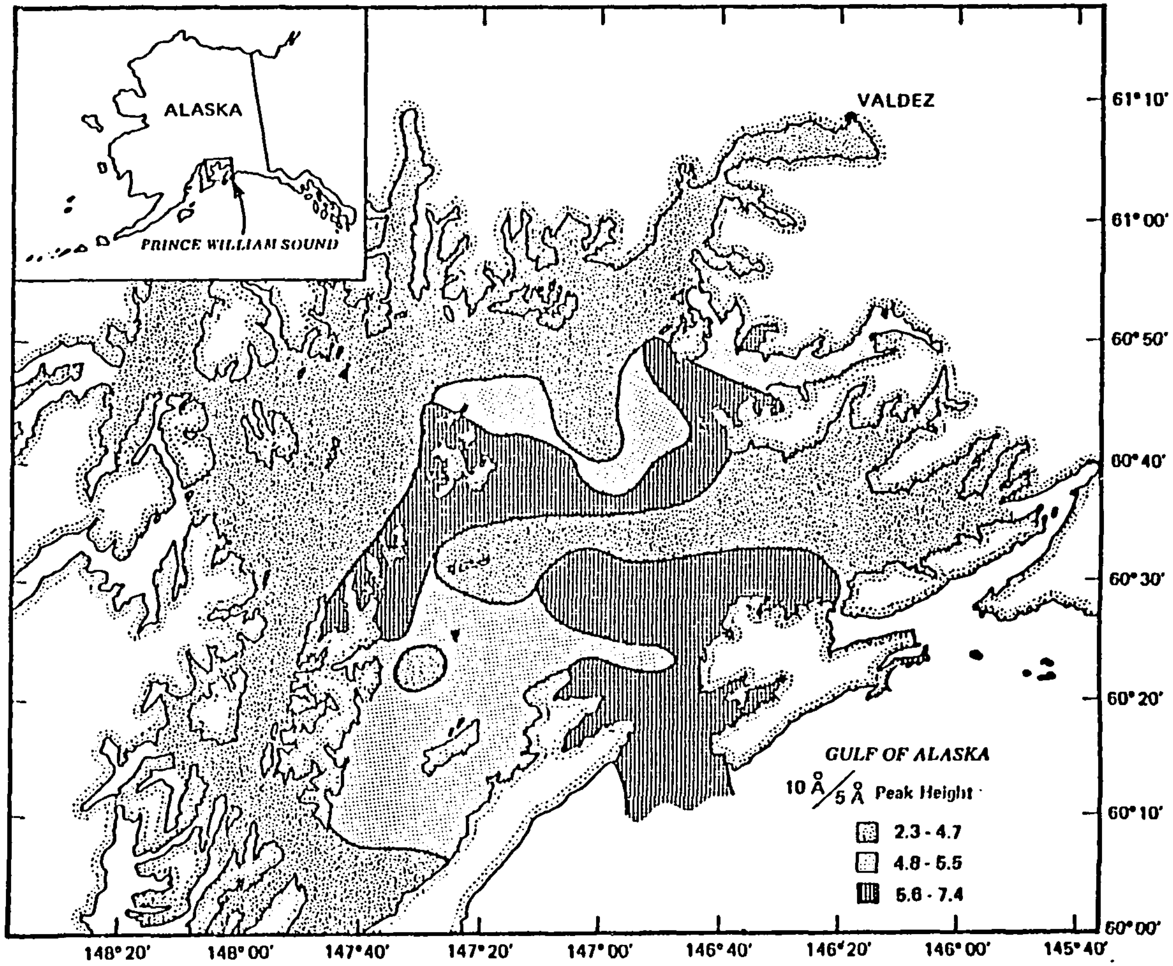

Figure 8. Distributional pattern of 10 Å/5 Å peak height ratios in Prince William Sound.

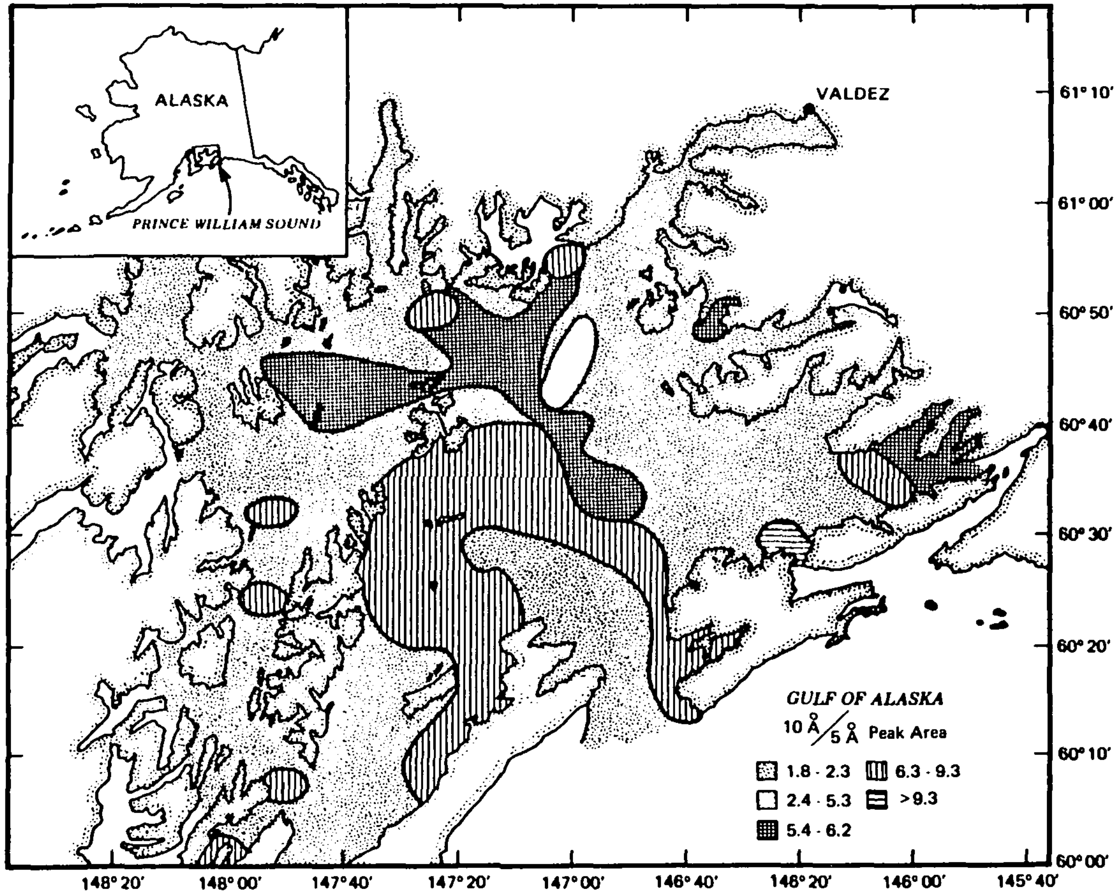

Figure 9. Distributional pattern of 10 Å/5 Å peak area ratios in Prince William Sound.

The regional variations in the 10 Å/5 Å peak area ratios exhibit an extremely large aerial variation (Figure 9). The highest ratios are present in the central Sound, which progressively give way to lower ratios near the periphery of the Sound. Presence of high values are locally identified in the northeastern and southwestern margins.

SEDIMENTATION RATES IN THE PRINCE WILLIAM SOUND AREA

On the basis of the slope of the least-squares fit of the exponential linear decrease of the excess ^{210}Pb activities with core depth in six gravity cores, the sedimentation rates were estimated for various locations in Prince William Sound (Figure 10). The total ^{210}Pb activities at specified core depths are listed in Table 3, and the excess ^{210}Pb values are listed in Appendix G. The excess ^{210}Pb activities are plotted versus core depth in Figure 11. The water content of the gravity core sections from the central basin of Prince William Sound are listed in Appendix H.

Regional variations in the sediment accumulation rates were identified. A net increase in the sedimentation rates from 0.30 to 0.57 cm/yr. was recognized from Hinchinbrook Entrance to the central Sound. Additionally, from Port Valdez to the Valdez Arm, there is a progressive increase in the accumulation rate from 0.11 to 0.52 cm/yr. Table 4 lists the accumulation rates (cm/yr.) in Prince William Sound and includes the mass sedimentation rates (g/cm^2/yr.), corresponding to the stations in the central and southern Sound.

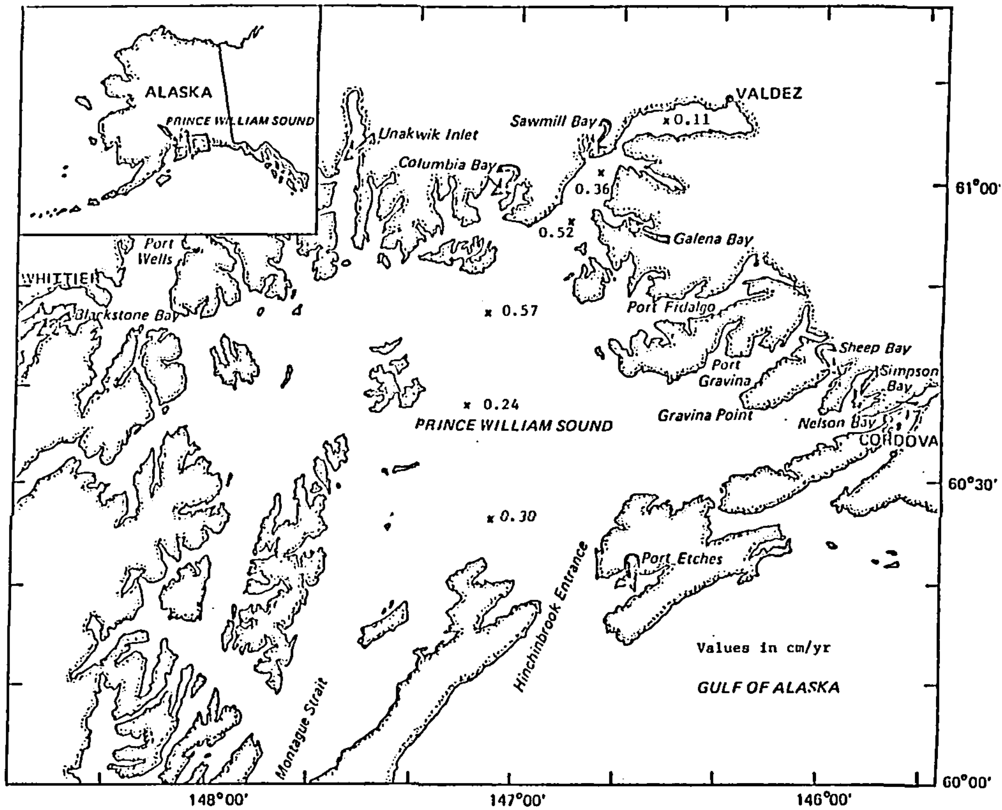

Figure 10. Sedimentation rates in Prince William Sound.

Table 3. Stratigraphic variations in the ^{210}Pb total activities (d/m/g) in gravity cores obtained from Prince William Sound, Port Valdez and Valdez Arm.

Core Number[1]	Core Depth (cm)	^{210}Pb (dpm/g)
PV 80-3	0-1	5.0 ± 0.14
	1-2	3.5 ± 0.10
	2-3	3.5 ± 0.10
	3-4	2.7 ± 0.14
	4-5	1.7 ± 0.10
	4-6	1.4 ± 0.10
	6-7	1.4 ± 0.10
	7-8	1.2 ± 0.07
	8-9	1.1 ± 0.08
	10-11	1.2 ± 0.09
	12-13	1.1 ± 0.08
	14-15	1.1 ± 0.06
	20-21	1.3 ± 0.09
	25-26	1.1 ± 0.07
	30-31	0.9 ± 0.05
	40-41	0.9 ± 0.05
	50-51	1.0 ± 0.05
	60-61	0.8 ± 0.08
	80-81	1.0 ± 0.05
	90-91	1.0 ± 0.08
PV 80-5	0-1	4.8 ± 0.40
	1-2	4.7 ± 0.20
	2-3	4.2 ± 0.20
	3-4	3.6 ± 0.10
	4-5	2.9 ± 0.20
	5-6	3.0 ± 0.10
	6-7	3.9 ± 0.08
	7-8	3.4 ± 0.10
	8-9	2.8 ± 0.10
	9-10	2.4 ± 0.20
	10-11	2.7 ± 0.10
	12-13	2.7 ± 0.10
	13-14	2.1 ± 0.10
	14-15	2.2 ± 0.15
	20-21	1.3 ± 0.07
	40-41	1.2 ± 0.10
	60-61	0.9 ± 0.05
	80-81	1.2 ± 0.06
	100-101	1.2 ± 0.06

[1]PV represents Port Valdez; PWS represents Prince William Sound.

Table 3. continued.

Core Number	Core Depth (cm)	^{210}Pb (dpm/g)
PV 80-6	0-1	4.9 ± 0.14
	1-2	4.4 ± 0.10
	2-3	4.6 ± 0.10
	3-4	4.4 ± 0.10
	4-5	4.0 ± 0.10
	5-6	3.0 ± 0.07
	6-7	3.0 ± 0.07
	7-8	3.2 ± 0.08
	9-10	3.0 ± 0.07
	10-11	2.6 ± 0.08
	12-13	3.7 ± 0.08
	13-14	3.1 ± 0.07
	20-21	3.0 ± 0.07
	25-26	1.9 ± 0.07
	30-31	1.9 ± 0.08
	35-36	1.4 ± 0.10
	40-41	1.6 ± 0.08
	55-56	1.1 ± 0.05
	60-61	1.4 ± 0.10
	70-71	1.2 ± 0.07
	78-79	1.1 ± 0.06
	80-81	1.3 ± 0.08
	90-91	1.2 ± 0.07
PWS 82-40	0-1	7.2 ± 0.02
	1-2	6.2 ± 0.02
	2-3	6.8 ± 0.05
	3-4	6.9 ± 0.03
	4-5	5.8 ± 0.04
	5-6	6.0 ± 0.04
	6-7	5.4 ± 0.05
	7-8	4.8 ± 0.04
	8-9	4.5 ± 0.04
	9-10	4.7 ± 0.04
	10-11	4.5 ± 0.05
	11-12	4.1 ± 0.04
	12-13	4.7 ± 0.04
	24-25	3.9 ± 0.05
	39-40	3.8 ± 0.05
	59-60	3.7 ± 0.06
	79-80	3.9 ± 0.07
	89-90	3.6 ± 0.06
	99-100	2.8 ± 0.07
	109-110	3.7 ± 0.06

Table 3. continued.

Core Number	Core Depth (cm)	^{210}Pb (dpm/g)
PWS 82-41	0-1	3.8 ± 0.04
	1-2	3.9 ± 0.04
	2-3	3.8 ± 0.04
	3-4	3.6 ± 0.04
	4-5	2.9 ± 0.04
	5-6	2.7 ± 0.04
	6-7	2.6 ± 0.05
	7-8	2.9 ± 0.05
	8-9	2.4 ± 0.06
	9-10	2.2 ± 0.06
	10-11	1.7 ± 0.07
	11-12	1.8 ± 0.07
	12-13	1.4 ± 0.08
	13-14	1.3 ± 0.06
	14-15	1.2 ± 0.07
	24-25	0.8 ± 0.09
	39-40	0.7 ± 0.09
	59-60	0.6 ± 0.10
	79-80	0.6 ± 0.10
PWS 82-43	0-1	2.9 ± 0.04
	1-2	2.4 ± 0.05
	2-3	2.7 ± 0.04
	3-4	2.5 ± 0.05
	4-5	2.4 ± 0.05
	5-6	2.0 ± 0.05
	6-7	1.5 ± 0.08
	7-8	2.2 ± 0.07
	8-9	1.7 ± 0.06
	9-10	1.8 ± 0.07
	10-11	1.4 ± 0.08
	11-12	1.4 ± 0.06
	17-18	1.3 ± 0.08
	24-25	0.9 ± 0.10
	39-40	0.7 ± 0.10
	59-60	0.6 ± 0.10
	79-80	0.7 ± 0.10

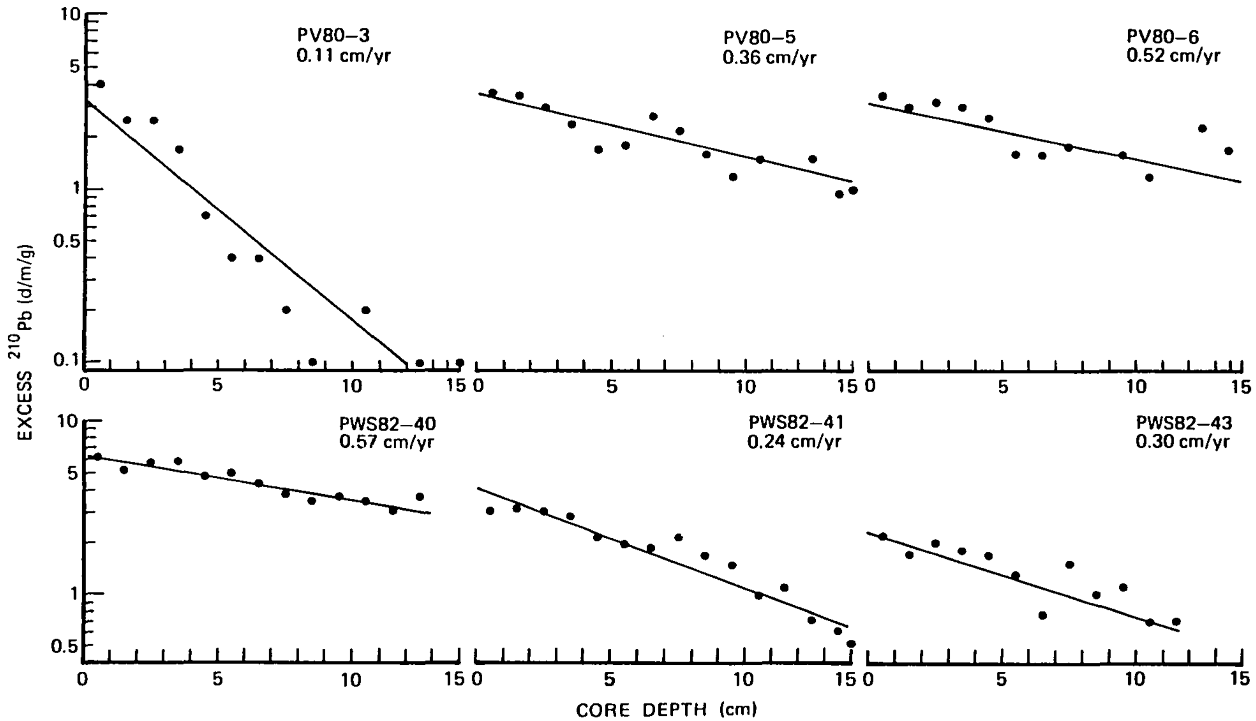

Figure 11. Profiles of excess ^{210}Pb with core depth. (Refer to Figure 3 for locations of the core samples.)

Table 4. Sedimentation rates of Prince William Sound. Included are the number and range of linear segments and correlation coefficients.

Sediment Core	Number of Linear Segments (n)	Linear Range (cm)	Intercept (a)	Slope (b)	Correlation Coefficient (r)	Sedimentation Rate (cm·yr^{-1})	Mass Sedimentation Rate (g·cm^{-2}·yr^{-1})
PV 80-3	20	0-91	1.17	-0.290	0.93	0.11	--[1]
PV 80-5	19	0-101	1.27	-0.086	0.90	0.36	--
PV 80-6	23	0-91	1.14	-0.060	0.72	0.52	--
PWS 82-40	20	0-110	1.84	-0.055	0.93	0.57	0.46
PWS 82-41	19	0-80	1.45	-0.131	0.96	0.24	0.20
PWS 82-43	17	0-80	0.83	-0.102	0.88	0.30	0.29

[1] Mass sedimentation rate values were not computed for Port Valdez due to insufficient data concerning the water content of the sediments.

HEAVY METALS IN SEDIMENTS OF PRINCE WILLIAM SOUND AND PORT VALDEZ

The total concentrations of a suite of heavy metals in the bottom sediments of Prince William Sound and Port Valdez are shown in Appendix H and Table 5, respectively. The fluxes of these metals into the sediments are given in Table 6. It was observed that some sediments from a few areas in Prince William Sound have unusually high concentrations of certain heavy metals.[1] In this context, the most obvious are some of the sediments off the northeastern portion of Knight Island and a few along the northeastern and western shores of Latouche Island (Figure 12) which have anomalously high values of Zn and Cu. Likewise, in a few sediments of Port Valdez, Cu and Mn appear in high concentrations. Additionally, sediments from the Knight Island Passage in the southwest corner of the Sound, located between Knight and Chenega islands (Figure 12), contain relatively high concentrations of Zn and Mn.

The concentrations of the metals that were extracted by the NH_2OH-HCL treatment from sediments of two type areas of Prince William Sound (e.g., Port Valdez and Chenega-Knight Island areas) are listed in Tables 7 and 8, respectively. Anomalously high values of extractable metals in the bottom sediments of the Sound are displayed in Figure 12. The sediments of Knight Island Passage are observed to contain high extractable Mn, whereas Port Valdez sediments generally have larger proportions of Zn and Mn.

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[1]Anomalously high concentrations of a metal is arbitrarily defined as being the concentrations of that metal above the mean value computed on the basis of all sediments.

Table 5. Total concentrations of heavy metals in surficial sediments of Port Valdez, Prince William Sound. All values are in µg/g except those of Fe whose concentrations are in µg/g × 10^4. Samples were obtained in September 1981.[1]

Station Number	Zn	Co	Cr	Cu	Ni	V	Pb	Mn	Fe
11	127	17	140	75	58	220	--	1,195	5.63
21	110	63	113	95	75	300	20	925	3.50
25	133	26	142	68	52	213	--	1,175	5.60
32	171	31	168	85	68	280	--	2,000	7.38
33	161	25	142	120	57	220	--	980	5.30
37	133	25	137	80	55	220	--	900	5.63
39	115	68	113	84	78	300	20	975	3.50
40	136	27	137	63	58	237	--	1,725	5.75
41	88	58	113	70	73	300	18	3,150	4.50
50	110	68	113	65	80	300	18	1,200	4.00
57	117	25	142	63	55	213	--	1,200	5.50
59	91	19	127	50	49	170	--	810	4.40
73(D-69)	136	22	137	60	52	213	--	980	5.13
77	127	26	142	70	57	213	--	1,570	5.75
Mean	125	36	133	75	62	243	19	1,342	5.00

[1]Dashes (--) signify metal was not analyzed for.

Table 6. Fluxes of heavy metals into sediments of central Prince William Sound and central Port Valdez. Values are in $\mu g/cm^2/yr$.

Element	Prince William Sound	Port Valdez
Zn	39	14
Co	11	4
Cr	32	15
Cu	17	8
Ni	15	7
V	69	27
Pb	6	2
Mn	265	148
Fe	12,800	5,500

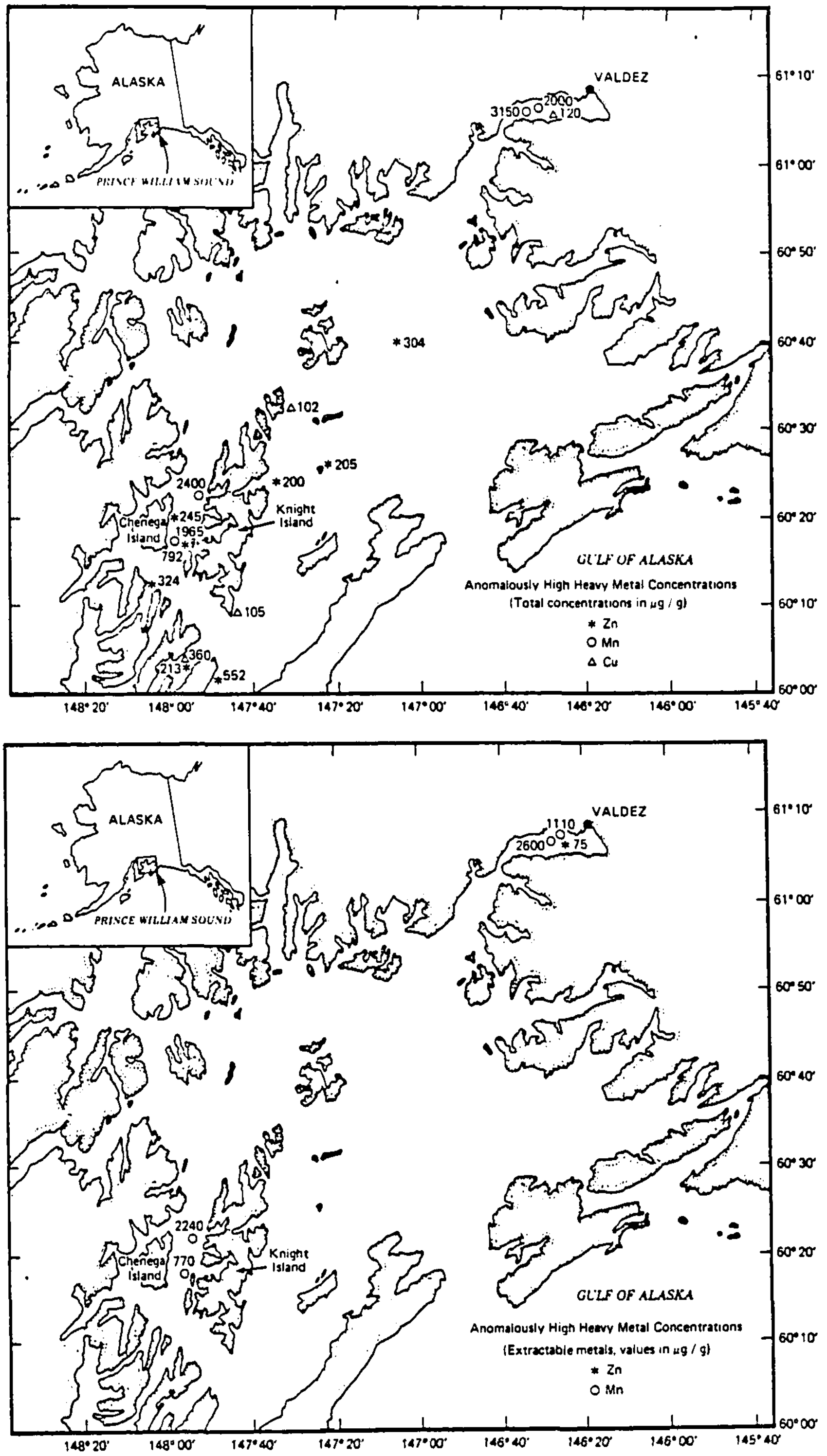


Figure 12. Locations of geochemical anomalies of total (top) and extractable (bottom) heavy metals in the sediment of Prince William Sound.

Table 7. Concentrations of extractable heavy metals in surficial sediments of Port Valdez, Prince William Sound. All values are in µg/g. Samples were obtained in September 1982.

Station Number	Zn	Co	Cr	Cu	Ni	V	Pb	Mn	Fe
11	20	9	3	28	13	4	11	140	2,900
21	21	9	3	32	12	5	11	245	3,260
25	27	10	2	26	11	8	12	165	3,360
32	23	10	3	33	12	5	11	280	3,500
33	75	8	3	25	9	8	13	60	3,620
37	27	11	3	29	11	7	11	410	3,610
39	21	10	2	28	10	4	12	330	3,420
40	30	14	4	29	12	11	13	1,110	4,840
41	34	17	4	33	13	15	13	2,600	5,460
50	27	11	3	25	11	10	13	550	3,720
57	29	11	3	28	11	6	12	490	3,550
59	38	6	3	25	9	4	11	65	3,600
73(D-69)	49	8	4	33	9	8	11	87	3,450
77	30	10	4	31	12	4	11	520	4,200
Mean	32	10	3	29	11	7	12	504	3,749

Table 8. Concentrations (μg/g) of some heavy metals in the extractable fraction of sediments from the Chenega-Knight Island area, Prince William Sound.

Sample Number	Zn	Co	Cr	Cu	Ni	V	Pb	Mn	Fe
PWS 82-2	30	6	2	14	9	5	12	87	3,390
PWS 82-5	27	9	3	16	6	15	12	400	3,290
PWS 82-7	21	6	2	13	5	8	9	230	2,470
PWS 82-9	24	9	2	17	7	16	12	440	3,260
PWS 82-12	24	10	2	18	6	18	12	510	3,360
PWS 82-13	34	8	3	20	9	10	15	230	3,780
PWS 82-14	12	6	1	11	5	6	8	515	1,510
PWS 82-17	24	9	3	21	8	15	14	175	2,430
PWS 82-20	21	9	3	17	8	14	15	770	2,760
PWS 82-21	14	8	2	17	5	8	9	467	1,800
PWS 82-23	21	15	2	14	10	11	11	2,240	2,760
PWS 82-26	16	7	2	15	5	10	11	280	2,020
PWS 82-31	7	2	1	5	2	3	7	105	1,120
PWS 82-33	24	7	3	11	6	11	15	70	2,300
PWS 82-37	8	6	2	6	5	7	9	140	890
Mean	20	8	2	14	6	10	11	506	2,418

In Appendices K and L, the total, extractable and percent extractable metals from the total sediment for the Chenega-Knight Island area and Port Valdez are listed. It is noted that with the exception of Mn and V, the concentrations of all metals in the extractable fractions are relatively higher in sediments of Port Valdez than in sediments of Prince William Sound.

The correlation coefficient matrix (Table 9) displays covariances or lack of it between heavy metals, grain size and clay minerals in the Chenega-Knight Island area of Prince William Sound. These correlations are significant at a 95% confidence level. The most notable positive correlation occurs between total and extractable Mn as well as total Co with the gravel content in sediments. Additionally, significant relationships exist between total Cu, Ni, V and extractable Zn, Cu and Fe with the clay content in sediments.

Table 9. Correlation coefficient matrix[1] between elements and element-lithological characteristics of sediments from the Chenega-Knight Island area, Prince William Sound.[2]

	Depth	Gravel	Sand	Silt	Clay	Expmin	Illite	Chlorite	TZn	TCu	TCo	TNi	TCr	TPb	TV	TMn	TFe	EZn	ECu	ECo	ENi	ECr	EPb	EV	EMn	EFe
Depth	1.0000																									
Gravel		1.0000																								
Sand	-0.7218		1.0000																							
Silt		-0.6792		1.0000																						
Clay	0.5925		-0.6092		1.0000																					
Expmin	0.7496	-0.9413		0.9810		1.0000																				
Illite							1.0000																			
Chlorite							-0.9870	1.0000																		
TZn						-0.9686			1.0000																	
TCu					0.5680					1.0000																
TCo		0.6529				-0.9934				0.6107	1.0000															
TNi	0.6468		-0.6031		0.6402	-0.9966				0.6568	0.7950	1.0000														
TCr						-0.6934							1.0000													
TPb						0.8660								1.0000												
TV					0.5924					0.6398		0.6133	0.6344		1.0000											
TMn		0.7465				-0.8819	0.5661	-0.5892							0.6781	1.0000										
TFe						-0.8660					0.6114	0.7607	0.7777				1.0000									
EZn	0.6022		-0.8642		0.7058													1.0000								
ECu	0.7655		-0.7471		0.5524	0.8660						0.7116					0.5538	0.7171	1.0000							
ECo						-0.7924						0.5506				0.7699			0.5760	1.0000						
ENi			-0.5999															0.7240	0.6404	0.7667	1.0000					
ECr			-0.6125			0.8660												0.6774	0.5980		0.5742	1.0000				
EPb			-0.6617			0.6547												0.7781	0.6487		0.7024	0.8813	1.0000			
EV	0.6541		-0.5651									0.7954							0.6942	0.6547		0.5899	0.6217	1.0000		
EMn		0.7518				-0.7750										0.9106				0.7584	0.5233				1.0000	
EFe	0.6678		-0.8453		0.6286							0.5419						0.9232	0.6732		0.6804		0.6747	0.6022		1.0000

[1]Correlation coefficient significant at 95% confidence level.

[2]Total metal portions are denoted with a prefix 'T' for each of the metals, whereas extractable portions of the metals are expressed with a prefix 'E' for each of the metals. EXPMIN stands for expandable clay minerals.

DISCUSSION

SEDIMENT SOURCES AND DEPOSITIONAL SITES

A number of investigators have shown that latitudinal variations in clay mineral compositions exist in the world oceans (Biscaye, 1965; Griffin et al., 1968; Rateev et al., 1969). It has been demonstrated that kaolinite is a typical "low latitude" mineral and that chlorite is a typical "high latitude" mineral. These latitudinal variations in clay mineralogy have been ascribed to the supply of clay minerals into the sea from continental soils of various climatic belts. An exception to this general latitudinal trend is the presence of unusually high concentrations of kaolinite in arctic marine sediments (Naidu et al., 1971).

This study demonstrates that the clay mineral assemblages of Prince William Sound, which consists mainly of illite and chlorite, correlate well with the latitudinal variations of clay minerals in the world oceans as suggested by Biscaye (1965) and Griffin et al. (1968). The paucity of kaolinite in the Prince William Sound sediments are consistent with the observations of Kunze et al. (1968) that the glacio-marine clays in southeast Alaska are a product of mild chemical leaching under glacial weathering conditions.

Characterizing the clay mineral composition of the <2 μm e.s.d. size fraction of recent marine sediments has proved extremely useful for determining sediment provenances and depositional sites of fine-grained particles in the marine environment (Biscaye, 1965; Griffin et al., 1968; Rateev et al., 1969; Gibbs, 1977; Molnia and Hein, 1982; Naidu and Mowatt, 1983; among many others).

On the basis of the distribution pattern of smectite in Prince William Sound, it is suggested that the clay minerals and by implication the fine-grained sediments entering the Sound are derived from two principal sources. As mentioned earlier, in the central Sound, the concentration of smectite in the sediments ranges from 1%-5%, whereas along the northern margin of the Sound smectite is consistently absent (Figure 4). Presumably, the smectite-bearing minerals of the central Sound are mainly derived from the influx of the Copper River plume into the Sound via the Gulf of Alaska. This contention is strengthened by the similar clay mineralogy of sediments of the Copper River bedload and those of the central Sound (Naidu et al., 1976; Molnia and Hein, 1982), the extension of the turbid plume of the Copper River into the Sound through the Gulf of Alaska (Burbank, 1974), and by the prevailing currents in the Gulf (Royer, 1981a). According to Royer (1981a), the Alaska Coastal Current moves in a counterclockwise direction along the coastal perimeter of the Gulf of Alaska. As this current moves westward, a major component of it is deflected into Prince William Sound through the Hawkins Island Cutoff and Hinchinbrook Entrance (Royer et al., 1979). It is suggested that the Coastal Current flowing at speeds of up to 1 knot (Royer, 1981b), can transport fine-grained suspended sediments from the northern Gulf to the Sound.

There is additional evidence to support the contention that clay minerals in central Prince William Sound are derived from the Copper River via the Gulf of Alaska. Through detailed study, Molnia and Hein (1982) have delineated the clay mineral suites of the central shelf of the Gulf of Alaska, extending from Icy Point to Prince William Sound. It was observed that directly south of the Copper River mouth, the concentrations of illite range from 55%-65%, which deviates markedly from the average illite content (37%) for the shelf. Kaolinite and chlorite concentrations on the shelf south of the Copper River are observed to range from 35%-48%, whereas the average for the entire shelf area is 61%. It is, therefore, implied in this study that the similar concentrations of illite and kaolinite and chlorite that are observed on the shelf area south of the Copper River and the contiguous central Prince William Sound are presumably related to a common source (e.g., the Copper River).

In another context, it would seem probable that an additional amount of smectite transported into central Prince William Sound may be derived from the submarine outcrop of the Yakataga Formation in the central Gulf of Alaska. The clays deposited locally around the outcrop have between 1%-9% smectite (Molnia and Fuller, 1977). Because of the limited geographic extent of the submarine outcrop and the local concentration of smectite observed, it is suggested by Naidu and Mowatt (1983) that the formation could not possibly constitute a major source of smectite into the central Gulf of Alaska and the adjacent Prince William Sound.

It is suggested that the distinct absence of smectite and kaolinite in clay mineral assemblages of the northern marginal area of Prince William Sound is attributable to their derivation from glacial flour of the adjacent hinterland. The predominant geologic formation in the area consists of the Valdez Group, which is composed largely of argillite, slate and graywacke. It has been demonstrated that the glacial flour derived from similar rock types, under conditions of minimal chemical leaching in the Alaskan sub-arctic, are typically composed of illite and chlorite with rare or no smectite and kaolinite (Kunze et al., 1968; O'Brien and Burrell, 1970). Clay mineral analysis by Naidu (in Feder et al., 1976) on intertidal and deltaic sediments at the head of Port Valdez in Prince William Sound, strongly supports the above concept, and is consistent with the suggested origin of clay minerals in the northern margin of the Sound.

The observed distributional pattern of illite-mica polytypes in Prince William Sound (Figure 7) is in accord with the aforementioned suggestions that the sediments in the Sound have been derived from two distinct souces. The 1 Md mica polytype predominates in sediments of the central Sound whereas along the northern margin of the basin, the sediments are mainly composed of 2M mica polytype. Yoder and Eugster (1955), concluded in their classic study that the 1 Md mica polytype is the stable form of mica at low temperatures (less than 200°C) and pressures (less than 15,000 p.s.i.), whereas the 2M mica polytype is the stable form at high temperatures (greater than 200°-300°C) and pressures (15,000 p.s.i.).

The analysis of the mica polytypes of the Prince William Sound clays suggests that the clays of the northern marginal area of the Sound are derived mostly from sedimentary, metasediments and high grade metamorphic rocks and that the clays of central Prince William Sound are derived chiefly from primary and low grade metamorphic rocks.

The aerial distribution pattern of the 10 Å/5 Å ratios of illite peaks reflects a regional variation in the nature of the illite structure. Weaver (1958) demonstrates that the 10 Å/5 Å ratios of peaks show a strong correlation with the trioctahedral (or biotitic) or dioctahedral (or muscovitic) derivation of illites. Generally speaking, the trioctahedral illites have higher 10 Å/5 Å ratios than dioctahedral illites.

It would seem that the central basinal area of Prince William Sound receives a relatively large flux of illites from biotitic-rich rocks (e.g., biotite schist, biotite granite), whereas the northern marginal area of the Sound is supplied with illites from muscovite-rich rocks (e.g., muscovite schist).

These conclusions are tentative pending more detailed study of the illite structures in the potential source rocks. Nonetheless, the regional variations observed in illite structures seem to further substantiate the suggestion that two primary sources of clays contribute to the sediments of Prince William Sound.

DEPOSITIONAL RATES AS DEDUCED BY ^{210}Pb STRATIGRAPHY

As mentioned earlier, a general increase in the ^{210}Pb-based sedimentation rates from 0.30 to 0.57 cm/yr. was identified from Hinchinbrook Entrance to central Prince William Sound (Figure 10). Presumably, this can be attributed to a net northward increase in the supply and deposition of sediments in the Sound from Hinchinbrook Entrance.

The data is consistent with the observation made by Burbank (1974) and Sharma et al. (1974) on the decrease northward of suspended sediments in Prince William Sound from 5.0 to 1.5 mg/l (Figure 13). Also, the amount of clays in the bottom sediment increases northward from 30%-50% (Figure 14) from Hinchinbrook Entrance to central Prince William Sound, further suggesting an increase in deposition of fine particles in the northerly direction. It is conceivable that in Prince William Sound there will be continuity northward, but with progressive decreased competency, in the inflow of the Copper River plume, as the plume flows into the wide expanse of the Sound from the narrow Hinchinbrook Channel. It is contended that the observed general increase in sedimentation rates from Hinchinbrook Entrance to central Prince William Sound is due to the progressively higher deposition of suspended sediments toward the central Sound consequent to the northward decreased flow competency. Additionally, it is possible that there is lower sediment deposition near the narrow Hinchinbrook Channel where higher turbulence may be expected to prevail.

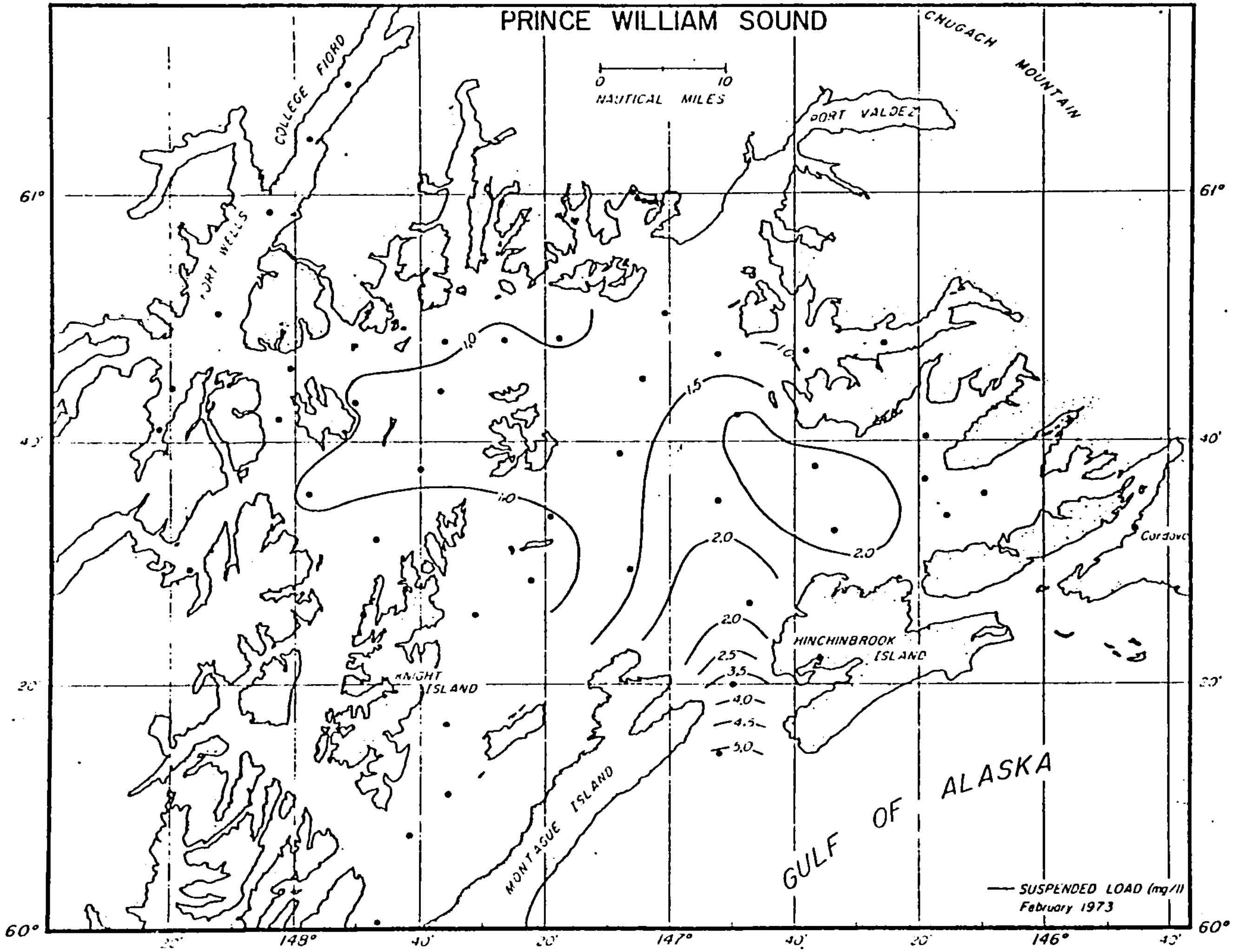


Figure 13. Surface suspended load distribution (mg/l) in Prince William Sound, February 1973.

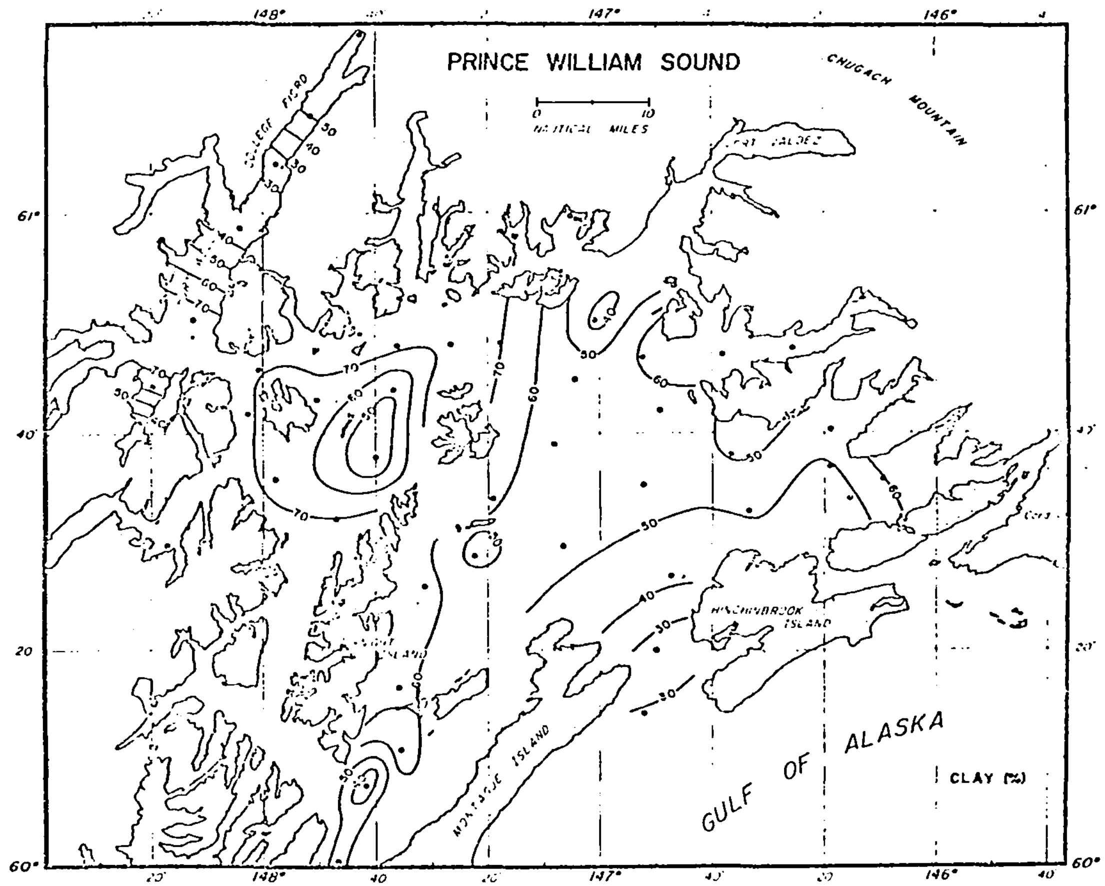


Figure 14. Percentage of clay in the surficial bottom sediments of Prince William Sound.

A progressive increase in sedimentation rates from 0.11 to 0.52 cm/yr. from Port Valdez to Valdez Arm in northeastern Prince William Sound (Figure 10) can be explained in terms of regional differences in sediment supply and water turbulence. The head of Port Valdez receives a relatively high flux of terrigenous sediments through glacial meltwaters and fluvial runoff. Much of this sediment supply appears to be in the form of dense suspended outflow from Valdez Glacier Stream and the Lowe River. The generally low sedimentation rate observed in this study for Port Valdez implies that most of the fine sediment discharged at the head of the Port is not deposited locally, probably as a result of intense tidal turbulence prevailing in the relatively narrow Port. It is proposed that the major proportion of the suspended sediments discharged into Port Valdez is caught in the tidal ebb flow and flushed out of the Port. I believe that the sediments thus exported from the Port are eventually deposited in Valdez Arm due to a possible decrease in the competency of the tidal ebb flow from the Port, through the Narrows, to the wider Arm.

Previous investigations of accumulation rates of sediments in sub-arctic inlets, bays and fjords have estimated the following values:

Saanich Inlet, B.C. (Murray et al., 1978)	1.05 cm/yr.
Saguenay Fjord, Quebec (Smith and Walton, 1980)	
--Head of Fjord	7.00 cm/yr.
--Inner Fjordal Basin	0.10 cm/yr.

Smeaten Bay, Alaska (unpublished data; cited by Burrell, 1982)	0.40 cm/yr.
Resurrection Bay, Alaska (Susan Sugai, pers. comm.)	0.16 cm/yr.
Present study:	
--Prince William Sound (average)	0.37 cm/yr.
--Port Valdez	0.11 cm/yr.
--Valdez Arm (average)	0.44 cm/yr.

It is, therefore, concluded that the sediment accumulation rates in central Prince William Sound and adjacent Port Valdez and Valdez Arm, with the exceptions of Saanich Inlet and the Head of Saguenay Fjord, correlate rather well with the rates obtained from previous studies in fjordal regions.

A number of studies have demonstrated that the vertical profiles of the ^{210}Pb excess activities in cores can provide useful information on the sedimentary processes of the basin from where the cores were collected (UNESCO, 1978).

The unsupported ^{210}Pb profiles of Prince William Sound and the Port Valdez area were carefully examined for stratigraphic breaks, in an attempt to detect submarine slumping corresponding to the 1964 earthquake and also to get an insight into the intensity of reworking of sediments by bioturbation. In all the cores analyzed, however, no such signal was identified. On the basis of the sedimentation rates estimated from the unsupported ^{210}Pb profiles and the length of the cores assayed for ^{210}Pb, it was assumed that sufficient lengths of cores were examined to cover the period a few years prior to 1964. It would seem, therefore, that any submarine slumping resulting from the 1964 earthquake did not significantly perturb sediment deposition at the points where the cores were collected (west of Port Valdez and Prince William Sound). However, lithological evidence of submarine slumping, most likely induced by the 1964 earthquake, are clearly displayed in cores retrieved from the eastern half and head of Port Valdez (Sharma, 1979; Klein and Naidu, unpublished). These cores include the presence of a turbidite sequence of well-defined graded beds with a basal gravel deposit overlain by a blanket of more recent mud. It is surmised that the impact of the 1964 earthquake on the marine depositional regime of the Prince William Sound area was restricted to local regions. As suggested by Plafker and Mayo (1965) and Coulter and Migliaccio (1966), submarine slumping, specially at the head of Port Valdez, was triggered by the presence of unstable deltaic sediments of the Lowe River.

In contrast to our observations in Prince William Sound, profiles of unsupported ^{210}Pb in several cores collected from the Boca de Quadra area in southeastern Alaska, indicate that submarine slumping is a common feature in that fjordal area (Burrell, 1982; Burrell, pers. comm).

In Figure 15, the structure and lithological variations in two gravity cores (used for ^{210}Pb stratigraphy) are exemplified in X-ray radiographs. These cores display a lack of distinct laminations and mottled structure, and clearly show the presence of homogeneous mud. Such a structure presumably conveys lack of both intense bioturbation,

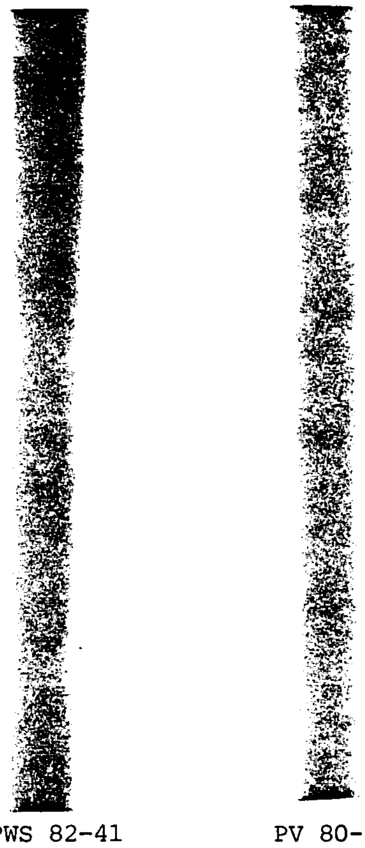


Figure 15. X-ray radiographs of gravity cores PWS 82-41 and PV 80-3 which were analyzed for sedimentation rates by ^{210}Pb analyses. Locations of these cores are shown in Figure 3.

and drastic variations in the depositional processes, such as one would expect to reflect in glacial varves.

Determining sedimentation rates within a given marine basin is of fundamental importance in elucidating time scales in which sedimentary processes have occurred. By combining the linear rate (cm/yr.) with the mean in situ density of the sediments (g/cm^3), the mass sedimentation rate ($g/cm^2/yr.$) can be computed. Additionally, knowing the concentrations of metals or of any other chemical, biological, or physical parameters in sediments along with the mass sedimentation rate, it can be possible to define the fluxes of the parameters into sediments from the overlying water column (e.g., flux = concentration of a defined parameter in the sediment multiplied by the mass sedimentation rate). The mass sedimentation rates provided in Table 4 for various geographic locations of Prince William Sound, should, therefore, serve a useful purpose in computing a mass balance for the Sound area. [See Appendix J.]

SEDIMENT GEOCHEMISTRY

Upon close examination of the data in Tables 5, 7 and 8 and Appendices K, L and M, it is apparent that there is a significant regional difference in the concentrations of a number of heavy metals in the Prince William Sound area. It seems that the sediments of the northern half of Knight Island Passage (north of latitude 60°21') and of the contiguous area in Dangerous Passage, with a few exceptions, generally have lower concentrations of all heavy metals than in the sediments south of these areas. The exception is the presence of anomalously high Mn in a few areas. Presumably, the high Mn values can be ascribed to the supply of sediments from the nearby Mn mineralization in the coastal belt of northeast Chenega Island (Kurtak, 1982).

On the basis of the anomalously high Mn values identified in a number of marine sediment samples from the Chenega-Knight Island area and Port Valdez (Figure 12), it is recommended that the onshore areas of eastern Chenega Island and western Knight Island as well as Port Valdez be further explored by field geologists for potential Mn ore bodies. The Mn mineralization northeast of Chenega Island probably does not extend southwestward to Dangerous Passage, as suggested by the consistent lack of Mn anomalies in sediments of the Passage (Figure 12).

The analysis of metals on the NH_2OH-HCL-CH_3COOH leachates showed anomalous values for Mn, both in the Chenega-Knight Island area as well as Port Valdez (Figure 12). No unusually high concentrations of Cu in the extractable phases of sediments were noted for the Chenega-Knight Island vicinity. This was surprising because a strong geochemical signal was expected, in light of Kurtak's (1982) findings of minor amounts of the mineral malachite [$Cu_2CO_3(OH)_2$] on quartz cobbles in streams draining the area. Thus, the occurrence of Cu mineralization in the northern Chenega Island area is probably not extensive.

The correlation coefficient matrix in Table 9 shows the statistically significant (at 95% confidence level) degrees of association that exist between metals, and between metals, textural attributes and clay minerals of marine sediments in the Chenega-Knight Island area. The correlations, whether positive or negative, must be interpreted with caution (Neville and Kennedy, 1964). A lack of a correlation or a negative correlation simply suggests an absence of statistical relations between two variables. As opposed to this, a positive correlation only suggests a covariance between two variables but "does not necessarily imply causation" (Neville and Kennedy, 1964; Kravitz, 1982). The discussion that follows is bound by the constraints mentioned above. Based on the covariances displayed in Table 9, it seems that both Co and Mn are closely associated with the gravelly particles of the sediments in the Chenega-Knight Island area. I have, however, no conclusive data at present to deduce what may be the chemical form(s) in which Mn and Co are bound in the gravels. Manganese could be associated with the coarse particles in any of the several possible discrete mineral phases, or as oxide and hydroxide encrustations on gravels, or even as discrete concretions (e.g., nodules). The high covariance of the extractable Mn and gravel indicates that significant portions of the Mn are partitioned in a "readily mobilizable" phase, presumably either as oxide/hydroxide or carbonate or both. Manganese has been reported to occur on the fluvial cobbles as Mn-oxide coatings in the vicinity of northeast Chenega Island (Kurtak, 1982).

Additionally, X-ray diffraction analysis of the Mn-mineralized rock from the above area has revealed the presence of the acid-soluble Mn mineral rhodochrosite ($MnCO_3$) and also of the less soluble Mn mineral pyromangite (Fe, Mn, Ca)SiO_3 (Roberts, 1982; as cited by Kurtak, 1982). The covariance of Co and Mn is probably attributable to the co-precipitation of Co with portions of Mn that presumably occurs as oxides/hydroxides on coarse particulates. This assumed Co-Mn association can also explain the significant positive correlation between Co and gravel in sediments of the Chenega-Knight Island area.

The present study indicates that the partitioning pattern of Mn in gravelly-silty-clays or sandy-gravel sediments of the Chenega-Knight Island area is significantly different than the pattern registered on muddy sediments of the adjacent Prince William Sound. Unlike the above island area, Mn in the central Sound is strongly correlatable with the clay size particles (Sharma, pers. comm.). In fact, the Mn-clay covariance is a common feature exhibited by nearshore deposits in Alaska, including those which have minor gravel intercalations (Naidu and Hood, 1972). It is contended that the strong Mn-gravel correlations in marine sediments of the Chenega-Knight Island area are quite uncommon and, therefore, is a geochemical 'peculiarity' for the area.

More recently, the Prince William Sound area has been increasingly subjected to a number of anthropogenic activities related to the export of crude oil from the southern terminus of the Alaska pipeline in Port Valdez. This has resulted in heavy tanker traffic. Additionally, treated ballast water is continuously discharged in low concentrations into Port Valdez. The consequences of these and other related activities on the ecosystem of Port Valdez and adjacent Prince William Sound are unknown. It is possible that the rate of discharge of heavy metal contaminants into the sediments may eventually increase to such an extent so as to impact the biological community. A few studies have been carried out both in the intertidal and subtidal areas of Port Valdez to gather environmental baseline data (Hood et al., 1973; Feder et al., 1976; Colonell, 1979; Shaw et al., 1980). It has been shown in Feder et al., (1976) that oil stranded on intertidal areas can be swiftly removed by tidal action. Additionally, Naidu et al. (1978) have suggested that heavy metals can be mobilized from sediment subsequent to the sediment hydrocarbon interaction. Results of a recently concluded long-term study (Shaw et al., 1983, in prep.) indicate that there is some degree of perturbation in the previously 'pristine' environment of Port Valdez. The concentrations and fluxes of nine metals which are listed in Tables 5, 7 and 8 and Appendices J, K, L, and M, and Table 6, respectively, should provide a benchmark for the monitoring of heavy metals in central Prince William Sound and the adjacent fjordal area of Port Valdez and Valdez Arm.

CONCLUSIONS

Based on the results of this investigation, the following conclusions seem warranted:

(1) The predominance of illite and chlorite and a notable absence of kaolinite in the glacio-marine sediments of Prince William Sound correlate well with the model of world-wide latitudinal trends of clay mineral assemblages as developed by Biscaye (1965) and Griffin et al. (1968). The clay minerals in Prince William Sound are derived from two predominant sources. The Copper River suspended sediment plume, moving into Prince William Sound from the Gulf of Alaska, deposits its clay minerals in the central basin. The latter mineral suite is traced by the constant presence of minor amounts of smectite and 1 Md mica polytype. Along the northern coast of the Sound, the sediments in the "fjordal assemblage" probably originate from the adjacent hinterland. The clay mineral suite in this region is devoid of smectite and contains 2M mica polytype. Although the concentration of smectite in the sediments is low, nonetheless, the presence or absence of it has been a useful means to elucidate the sources and depositional sites of fine-grained sediments in Prince William Sound.

(2) Aerial variations in the ^{210}Pb-based sedimentation rates were recognized. A general northward increase in the rates from 0.30 to 0.57 cm/yr. was identified from Hinchinbrook Entrance to the central Sound. This is presumably a result of the northward increase in the sediment deposition as the competency of the flow of the turbid Copper River plume decreases from Hinchinbrook Entrance to central Prince William Sound. A progressive increase in the sedimentation rates from 0.11 to 0.52 cm/yr. from Port Valdez to Valdez Arm was also observed. It is probable that fine-grained sediments discharged into the head of Port Valdez by rivers and glacial meltwaters, are not deposited locally due to tidal turbulence. These fine particulates are apparently transported from the Port by the ebb tide and deposited in Valdez Arm.

(3) Geochemical anomalies were sought for nine heavy metals (Zn, Co, Ni, Cu, Cr, Pb, V, Mn, Fe) in Prince William Sound sediments in order to define targets for exploration of onshore mineralization. It is concluded that the bedrock in the Chenega-Knight Island region is probably mineralized in Zn, Cu, and Mn, whereas in Port Valdez, the onshore areas are presumably mineralized with Mn. The existence of a strong Mn-gravel correlation in the marine sediments of the Chenega-Knight Island area is unusual for Prince William Sound

and may be considered a geochemical "anomaly" for the region. This study has shown that the use of geochemical anomalies of metals in the sediment of Prince William Sound is an efficient tool for elucidating potential regions of onshore mineralization in this coastal embayment.

APPENDICES

APPENDIX A1. Locations of surficial bottom sediment samples used in this study.

Sample Number[1]	Latitude N.	Longitude W.	Water Depth (m)
PWS 66-3	60°34.8'	146°55.1'	438
PWS 66-6	60°48.5'	147°16.2'	393
PWS 66-11	61°00.5'	147°16.2'	160
PWS 66-16	61°08.7'	147°32.7'	178
PWS 66-17	60°48.9'	147°38.0'	138
PWS 66-19	60°38.2'	147°49.0'	215
PWS 66-20	60°30.2'	147°52.2'	329
PWS 66-21	60°22.5'	147°55.8'	299
PWS 66-22	60°14.9'	147°59.0'	570
PWS 66-23	60°08.1'	147°51.4'	283
PWS 73-2	60°47.1'	146°38.0'	160
PWS 73-11	60°46.0'	148°01.0'	388
PWS 73-12	60°50.4'	148°12.5'	422
PWS 73-13	60°58.7'	148°04.1'	283
PWS 73-14	61°04.6'	147°57.7'	73
PWS 73-15	61°09.0'	147°51.5'	219
PWS 73-16	60°44.3'	148°19.6'	268
PWS 73-20	60°32.1'	147°47.1'	713
PWS 73-22	60°34.0'	147°19.2'	190
PWS 73-23	60°29.5'	147°06.5'	212
PWS 73-26	60°14.1'	146°52.1'	248
PWS 73-27	60°32.7'	146°33.7'	128
PWS 73-28	60°38.0'	146°36.5'	55
PWS 73-32	60°50.0'	147°01.0'	365
PWS 73-33	60°45.0'	147°04.2'	453
PWS 79-1	60°03.8'	147°55.7'	219
PWS 79-2	60°05.9'	147°32.0'	110
PWS 79-3	60°09.0'	147°38.1'	121
PWS 79-4	60°18.7'	147°16.2'	128
PWS 79-5	60°12.5'	147°23.5'	55
PWS 79-6	60°23.0'	147°30.0'	163
PWS 79-7	60°24.1'	147°16.2'	121
PWS 79-8	60°24.6'	147°05.0'	166
PWS 79-9	60°27.6'	147°13.4'	207
PWS 79-10	60°30.2'	147°15.7'	168
PWS 79-11	60°28.0'	147°24.8'	117
PWS 79-12	60°27.8'	147°34.5'	106
PWS 79-13	60°36.0'	147°29.7'	197
PWS 79-14	60°38.9'	147°15.4'	113

[1]PWS represents Prince William Sound. PV represents Port Valdez.

APPENDIX A1. continued.

Sample Number	Latitude N.	Longitude W.	Water Depth (m)
PWS 79-15	60°39.1'	147°07.8'	215
PWS 79-16	60°42.7'	147°15.6'	160
PWS 79-17	60°46.2'	147°15.6'	355
PWS 79-18	60°51.1'	147°13.5'	66
PWS 79-19	60°53.3'	146°58.8'	358
PWS 79-20	60°55.2'	147°05.0'	292
PWS 79-21	60°59.3'	147°05.4'	205
PWS 79-22	60°55.4'	146°52.7'	358
PWS 79-23	60°53.2'	146°43.2'	22
PWS 79-24	60°50.6'	146°39.4'	47
PWS 79-25	60°45.2'	146°51.1'	384
PWS 79-26	60°38.5'	146°45.0'	260
PWS 79-27	60°38.5'	146°56.0'	420
PWS 79-28	60°30.9'	146°25.1'	55
PWS 79-29	60°31.2'	146°50.0'	422
PWS 79-30	60°24.0'	146°50.0'	285
PWS 80-1	60°02.5'	147°48.5'	303
PWS 80-2	60°14.5'	148°06.2'	466
PWS 80-3	60°18.2'	147°59.0'	530
PWS 80-4	60°18.3'	147°53.4'	92
PWS 80-5	60°19.9'	147°59.7'	83
PWS 80-6	60°24.5'	147°58.3'	91
PWS 80-7	60°34.2'	147°35.7'	154
PWS 80-8	60°52.1'	147°23.6'	102
PWS 80-9	60°48.6'	146°36.0'	90
PWS 80-10	60°50.5'	146°35.0'	100
PWS 80-12	60°47.2'	146°29.6'	184
PWS 80-13	60°50.3'	146°29.6'	55
PWS 80-14	60°42.8'	146°20.6'	32
PWS 80-15	60°37.7'	146°08.0'	84
PWS 80-16	60°39.5'	146°00.6'	59
PWS 80-17	60°35.0'	146°11.5'	136
PWS 80-18	60°20.7'	146°06.9'	30
PWS 80-19	60°40.0'	147°00.0'	100
PWS 80-20	60°19.4'	147°37.7'	180
PWS 80-21	60°17.7'	147°40.3'	95
PWS 80-22	60°11.3'	147°43.2'	120
PWS 80-23	60°01.2'	147°59.4'	46
PWS 80-24	59°58.6'	148°02.4'	39
PWS 80-25	60°01.6'	148°03.4'	51
PWS 81-1	60°46.5'	147°25.0'	445
PWS 81-2	60°46.0'	147°35.0'	555

APPENDIX A1. continued.

Sample Number	Latitude N.	Longitude W.	Water Depth (m)
PWS 81-3	60°44.0'	147°43.0'	457
PWS 81-4	60°38.0'	147°45.0'	732
PWS 81-5	60°32.0'	147°44.0'	582
PWS 81-6	60°35.0'	147°42.0'	695
PWS 81-7	60°40.0'	147°36.0'	330
PWS 82-1	60°15.1'	148°06.9'	335
PWS 82-2	60°16.1'	148°05.3'	190
PWS 82-3	60°16.1'	148°05.0'	168
PWS 82-4	60°16.1'	148°04.3'	201
PWS 82-5	60°16.1'	148°03.3'	338
PWS 82-7	60°16.1'	148°01.3'	484
PWS 82-8	60°16.0'	148°00.2'	592
PWS 82-9	60°16.1'	147°59.4'	574
PWS 82-10	60°16.1'	147°58.3'	571
PWS 82-12	60°17.5'	147°59.0'	508
PWS 82-13	60°18.8'	147°58.5'	494
PWS 82-14	60°19.8'	147°59.6'	155
PWS 82-15	60°19.7'	147°58.9'	366
PWS 82-16	60°19.7'	147°58.0'	450
PWS 82-17	60°19.7'	147°57.0'	366
PWS 82-18	60°19.7'	147°56.0'	389
PWS 82-19	60°19.7'	147°55.0'	102
PWS 82-20	60°20.9'	147°57.8'	355
PWS 82-21	60°22.6'	147°57.0'	373
PWS 82-22	60°24.1'	147°52.9'	256
PWS 82-23	60°24.1'	147°54.4'	287
PWS 82-24	60°24.2'	147°55.3'	376
PWS 82-25	60°24.1'	147°56.4'	250
PWS 82-26	60°24.2'	147°57.4'	121
PWS 82-27	60°24.2'	147°58.5'	168
PWS 82-28	60°24.2'	147°59.3'	175
PWS 82-29	60°23.9'	148°00.0'	113
PWS 82-30	60°23.6'	148°00.6'	88
PWS 82-31	60°23.3'	148°01.9'	58
PWS 82-32	60°23.0'	148°02.7'	110
PWS 82-33	60°22.8'	148°03.6'	146
PWS 82-34	60°22.5'	148°04.5'	107
PWS 82-35	60°22.0'	148°05.3'	65
PWS 82-36	60°21.9'	148°06.0'	76
PWS 82-37	60°21.7'	148°06.9'	46

APPENDIX A1. continued.

Sample Number	Latitude N.	Longitude W.	Water Depth (m)
PV 11	61°06.4'	146°20.0'	200
PV 21	61°06.4'	146°22.5'	234
PV 25	61°05.5'	146°23.4'	234
PV 32	61°06.4'	146°25.3'	232
PV 33	61°05.4'	146°23.1'	66
PV 37	61°05.6'	146°22.5'	166
PV 39	61°07.2'	146°28.7'	139
PV 40	61°06.3'	146°28.7'	235
PV 41	61°05.5'	146°28.7'	235
PV 50	61°06.4'	146°35.7'	247
PV 56	61°03.9'	146°40.3'	239
PV 57	61°05.7'	146°22.7'	232
PV 59	61°05.2'	146°23.8'	54
PV 73 (D69)	61°05.4'	146°23.8'	248
PV 77	61°05.8'	146°22.8'	232

APPENDIX A2. Station locations of gravity cores used for ^{210}Pb dating.

Station Number	Latitude N.	Longitude W.	Water Depth (m)
PV 80-3	61°06.35'	146°32.50'	198
PV 80-5	61°02.00'	146°42.50'	312
PV 80-6	60°57.00'	146°50.50'	379
PWS 82-40	60°47.00'	147°00.00'	384
PWS 82-41	60°38.68'	147°09.99'	230
PWS 82-43	60°27.04'	147°04.93'	184

APPENDIX B. ^{208}Po and ^{210}Po counts for ^{210}Pb geochronology of gravity cores in the central basin of Prince William Sound.

Core Number	Depth (cm)	^{208}Po	^{210}Po
PWS 82-40	0-1	4,568	3,460
	1-2	4,157	2,709
	2-3	4,954	3,535
	3-4	3,508	2,542
	4-5	1,802	1,133
	5-6	1,549	1,007
	6-7	1,051	609
	7-8	1,098	565
	8-9	1,635	789
	9-10	1,617	821
	10-11	1,189	582
	11-12	2,303	1,026
	12-13	1,500	755
	24-25	1,815	767
	39-40	1,064	430
	59-60	1,495	590
	79-80	1,672	707
	89-90	1,706	672
	99-100	1,227	379
	109-110	1,102	442
PWS 82-41	0-1	2,209	883
	1-2	2,718	1,130
	2-3	2,831	1,143
	3-4	1,895	725
	4-5	2,455	766
	5-6	2,301	667
	6-7	1,618	443
	7-8	1,446	447
	8-9	1,514	396
	9-10	1,498	349
	10-11	1,288	237
	11-12	1,373	269
	12-13	1,266	192
	13-14	2,091	284
	14-15	2,012	260
	24-25	1,737	143
	39-40	1,570	113
	59-60	1,566	101
	79-80	2,237	147

APPENDIX B. continued.

Core Number	Depth (cm)	^{208}Po	^{210}Po
PWS 82-43	0-1	2,688	835
	1-2	2,401	611
	2-3	2,420	687
	3-4	2,114	549
	4-5	1,662	425
	5-6	2,088	455
	6-7	1,177	196
	7-8	1,075	255
	8-9	1,754	331
	9-10	1,109	215
	10-11	1,107	172
	11-12	1,940	294
	17-18	1,235	169
	24-25	1,891	189
	39-40	1,375	107
	59-60	1,199	75
	79-80	1,313	106

APPENDIX C. Clay mineral composition (weighted peak area %) of the <2 μm fraction of sediments of Prince William Sound.

Station[1] Number	Expandable Minerals	Illite	Chlorite	Kaolinite	Kaolinite + Chlorite
PWS 66-3	1	64	--	--	35
PWS 66-6	0	56	--	--	44
PWS 66-16	0	52	--	--	48
PWS 66-17	3	57	--	--	40
PWS 66-19	0	53	--	--	47
PWS 66-20	4	59	--	--	37
PWS 66-21	3	54	--	--	43
PWS 66-22	0	53	--	--	47
PWS 66-23	0	64	--	--	36
PWS 73-2	1	48	--	--	51
PWS 73-11	2	68	--	--	30
PWS 73-12	0	47	--	--	53
PWS 73-13	0	56	--	--	44
PWS 73-14	0	60	--	--	40
PWS 73-15	0	59	--	--	41
PWS 73-16	0	60	--	--	40
PWS 73-20	2	50	--	--	48
PWS 73-22	2	68	--	--	30
PWS 73-23	1	64	--	--	35
PWS 73-26	2	71	--	--	27
PWS 73-27	2	68	--	--	30
PWS 73-28	2	65	--	--	33
PWS 73-32	0	58	--	--	42
PWS 73-33	0	40	--	--	60
PWS 79-1	4	45	48	3	--
PWS 79-2	4	52	40	4	--
PWS 79-3	3	54	37	6	--
PWS 79-4	5	52	38	5	--
PWS 79-5	4	55	37	4	--
PWS 79-6	4	56	37	3	--
PWS 79-7	4	55	36	5	--
PWS 79-8	5	59	31	5	--
PWS 79-9	3	62	31	4	--
PWS 79-10	5	53	37	5	--
PWS 79-11	3	59	34	4	--
PWS 79-12	4	60	30	6	--
PWS 79-13	2	57	36	5	--
PWS 79-14	3	56	35	6	--

[1]PWS represents Prince William Sound; PV represents Port Valdez; PE represents Port Etches.

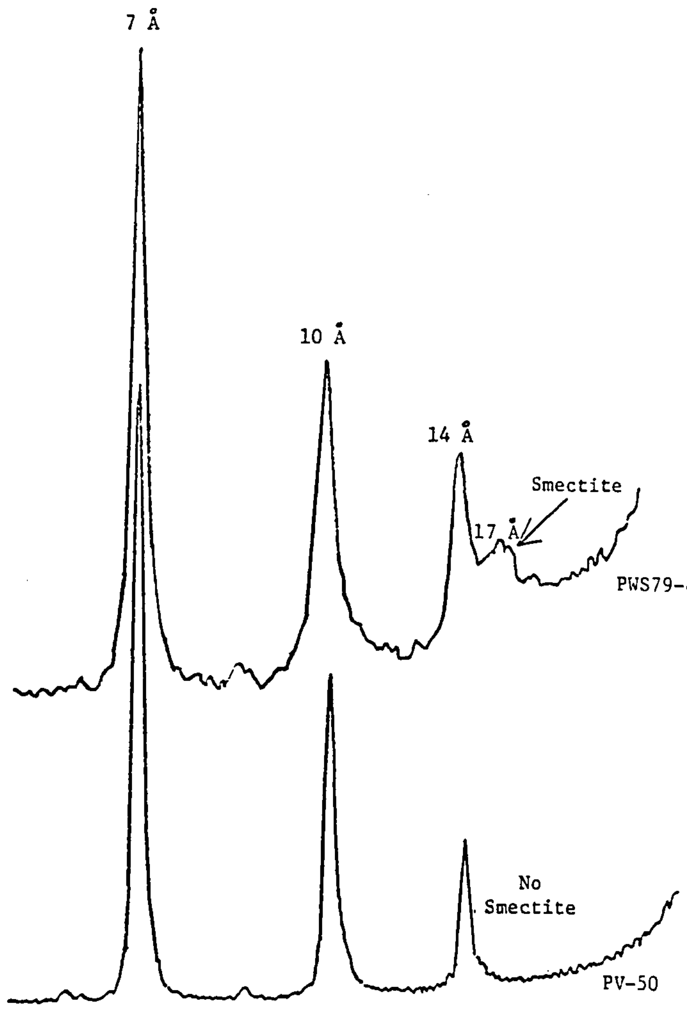
APPENDIX C. continued.

Station Number	Expandable Minerals	Illite	Chlorite	Kaolinite	Kaolinite + Chlorite
PWS 79-15	2	65	29	4	--
PWS 79-16	2	61	34	3	--
PWS 79-17	3	62	31	4	--
PWS 79-18	0	56	42	2	--
PWS 79-19	0	52	46	2	--
PWS 79-20	0	46	52	2	--
PWS 79-21	0	50	48	2	--
PWS 79-22	0	52	46	2	--
PWS 79-23	3	58	37	2	--
PWS 79-24	3	59	35	3	--
PWS 79-25	3	59	33	5	--
PWS 79-26	3	62	32	3	--
PWS 79-27	1	60	36	3	--
PWS 79-28	4	58	35	3	--
PWS 79-29	3	59	34	4	--
PWS 79-30	2	63	32	3	--
PWS 80-1	4	54	--	--	42
PWS 80-2	2	47	--	--	51
PWS 80-3	2	56	--	--	42
PWS 80-4	4	58	--	--	38
PWS 80-5	3	62	--	--	35
PWS 80-6	2	52	--	--	46
PWS 80-7	5	56	--	--	38
PWS 80-8	2	61	--	--	37
PWS 80-9	5	61	--	--	34
PWS 80-10	4	56	--	--	40
PWS 80-12	4	56	--	--	40
PWS 80-13	2	54	--	--	44
PWS 80-14	4	60	--	--	36
PWS 80-15	2	58	--	--	40
PWS 80-16	4	55	--	--	41
PWS 80-17	2	49	--	--	49
PWS 80-18	2	62	--	--	36
PWS 80-19	2	59	--	--	39
PWS 80-20	1	52	--	--	47
PWS 80-21	2	50	--	--	48
PWS 80-22	2	52	--	--	46
PWS 80-23	4	51	--	--	45
PWS 80-24	2	49	--	--	49
PWS 80-25	2	55	--	--	43

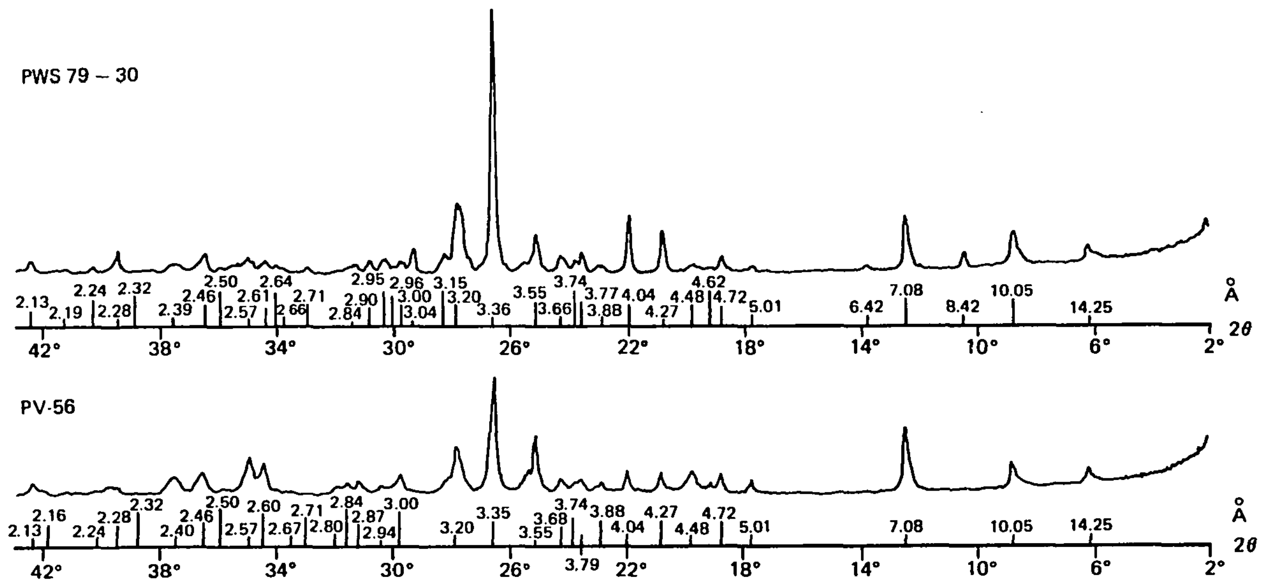
APPENDIX C. continued.

Station Number	Expandable Minerals	Illite	Chlorite	Kaolinite	Kaolinite + Chlorite
PWS 81-1	3	59	--	--	38
PWS 81-2	3	56	--	--	41
PWS 81-3	3	57	--	--	40
PWS 81-4	3	56	--	--	41
PWS 81-5	3	52	--	--	45
PWS 81-6	2	55	--	--	43
PWS 81-7	3	57	--	--	40
PWS 82-2	0	38	--	--	61
PWS 82-5	0	48	--	--	51
PWS 82-7	0	49	--	--	50
PWS 82-9	0	47	--	--	42
PWS 82-12	0	53	--	--	45
PWS 82-13	0	45	--	--	54
PWS 82-14	0	57	--	--	41
PWS 82-17	0	49	--	--	50
PWS 82-20	3	55	--	--	40
PWS 82-21	2	47	--	--	50
PWS 82-23	1	57	--	--	41
PWS 82-26	0	58	--	--	40
PWS 82-31	0	51	--	--	48
PWS 82-33	0	50	--	--	49
PWS 82-37	0	44	--	--	55
PV 50	0	53	--	--	47
PV 56	0	52	--	--	48
PE 9	3	45	--	--	52
PE 13	2	68	--	--	30

APPENDIX D. X-ray diffractograms of sediment samples from northern and central Prince William Sound, displaying the variation in the smectite content of the sediments.



APPENDIX E. X-ray diffractograms (unoriented sample) from northern (PV-56) and central (PWS 79-30) Prince William Sound, displaying the variations of mica polytypes in the sediment.



APPENDIX F . Illite 10 Å/5 Å ratios.

Sample[1] Number	10 Å (Height cm)	5 Å (Height cm)	10 Å (Area)	5 Å (Area)	10Å/5Å (Height cm)	10Å/5Å (Area)
PWS 66-3	7.4	1.8	22	4	4.1	5.5
PWS 66-6	8.2	1.8	22	4	4.6	5.5
PWS 66-16	9.4	2.8	23	8	3.4	2.9
PWS 66-17	8.5	1.8	26	6	4.7	4.3
PWS 66-19	7.6	2.0	18	6	3.8	3.0
PWS 66-20	7.8	2.2	27	8	3.5	3.4
PWS 66-21	7.6	1.8	23	7	4.2	3.3
PWS 66-22	5.6	1.4	12	4	4.0	3.0
PWS 66-23	4.7	1.1	17	2	4.3	8.5
PWS 73-2	3.4	0.5	10	2	6.8	5.0
PWS 73-11	6.6	1.5	18	5	4.4	3.6
PWS 73-12	9.4	3.6	20	5	2.6	4.0
PWS 73-13	5.6	1.9	9	5	2.9	1.8
PWS 73-14	7.7	2.0	15	6	3.9	2.5
PWS 73-15	9.2	2.8	14	3	3.3	4.7
PWS 73-16	5.1	1.5	10	3	3.4	3.3
PWS 73-20	4.5	1.0	14	2	4.5	7.0
PWS 73-22	5.6	1.3	19	3	4.3	6.3
PWS 73-23	4.8	0.7	16	4	6.9	4.0
PWS 73-26	6.7	1.1	24	5	6.1	4.8
PWS 73-27	5.3	0.9	16	4	6.2	4.0
PWS 73-28	5.0	1.2	18	5	4.2	3 6
PWS 73-32	5.9	1.8	11	5	3.3	2.2
PWS 73-33	6.5	2.1	11	6	3.1	1.8
PWS 79-1	6.5	1.6	14	3	4.1	4.7
PWS 79-2	5.1	1.2	15	3	4.3	5.0
PWS 79-3	6.4	1.3	17	4	4.9	4.3
PWS 79-4	7.6	1.6	19	3	4.8	6.3
PWS 79-5	9.8	1.9	25	3	5.2	8.3
PWS 79-6	9.7	2.4	25	3	4.0	8.3
PWS 79-7	8.7	1.6	20	3	5.4	6.7
PWS 79-8	7.0	1.3	14	3	5.4	4.7
PWS 79-9	9.7	1.9	28	4	5.1	7.0
PWS 79-10	7.7	1.9	20	7	4.1	2.9
PWS 79-11	14.4	2.6	39	6	5.5	6.5
PWS 79-12	9.2	1.3	24	3	7.1	8.0
PWS 79-13	12.2	2.0	28	3	6.1	9.3
PWS 79-14	8.4	1.5	20	3	5.6	6.7
PWS 79-15	13.7	2.1	39	4	6.5	9.8
PWS 79-16	10.1	1.4	27	7	7.2	3.9
PWS 79-17	10.8	2.1	30	5	5.1	6.0

[1]PWS represents Prince William Sound; PV represents Port Valdez; PE represents Port Etches.

APPENDIX F . continued.

Sample Number	10 Å (Height cm)	5 Å (Height cm)	10 Å (Area)	5 Å (Area)	10Å/5Å (Height cm)	10Å/5Å (Area)
PWS 79-18	12.8	2.9	27	6	4.4	4.5
PWS 79-19	10.6	3.8	25	5	2.8	5.0
PWS 79-20	6.8	2.9	13	2	2.3	6.5
PWS 79-21	9.1	3.2	17	3	2.8	5.7
PWS 79-22	8.0	2.2	17	5	3.6	3.4
PWS 79-23	5.5	1.1	15	3	5.0	5.0
PWS 79-24	5.7	1.0	18	5	5.7	3.6
PWS 79-25	9.1	1.7	23	5	5.4	4.6
PWS 79-26	11.1	1.5	30	7	7.4	4.3
PWS 79-27	9.5	2.0	25	5	4.8	5.0
PWS 79-28	10.1	1.5	28	2	6.7	14.0
PWS 79-29	9.9	1.6	27	3	6.2	9.0
PWS 79-30	3.3	0.6	10	3	5.5	3.3
PWS 80-1	6.9	1.7	22	6	4.1	3.7
PWS 80-2	7.8	2.1	22	6	3.7	3.7
PWS 80-3	7.9	2.0	25	6	4.0	4.2
PWS 80-4	5.8	1.7	20	4	3.4	5.0
PWS 80-5	11.5	3.0	39	9	3.8	4.3
PWS 80-6	9.9	3.0	27	4	3.3	6.8
PWS 80-7	6.3	1.6	21	6	3.9	3.5
PWS 80-8	8.5	2.6	27	4	3.3	6.8
PWS 80-9	6.8	1.3	26	4	5.2	6.5
PWS 80-10	6.0	0.9	16	3	6.7	5.3
PWS 80-12	10.1	1.9	27	6	5.3	4.5
PWS 80-13	8.7	1.8	30	5	4.8	6.0
PWS 80-14	9.6	1.7	33	7	5.6	4.7
PWS 80-15	11.2	2.6	35	5	4.3	7.0
PWS 80-16	7.1	1.7	22	4	4.2	5.5
PWS 80-17	8.6	1.8	24	6	4.8	4.0
PWS 80-18	7.6	1.2	26	6	6.3	4.3
PWS 80-19	9.3	2.3	28	5	4.0	5.6
PWS 80-20	8.0	1.5	28	7	5.3	4.0
PWS 80-21	5.7	1.1	22	8	5.2	2.8
PWS 80-22	6.3	1.1	21	4	5.7	5.3
PWS 80-23	7.1	1.8	21	3	3.9	7.0
PWS 80-24	3.7	1.0	11	3	3.7	3.7
PWS 80-25	6.0	1.5	21	3	4.0	7.0
PWS 81-1	11.6	2.3	39	9	5.0	4.3
PWS 81-2	10.1	2.5	38	7	4.0	5.4
PWS 81-3	9.7	2.3	31	5	4.2	6.2

APPENDIX F. continued.

Sample Number	10 Å (Height cm)	5 Å (Height cm)	10 Å (Area)	5 Å (Area)	10Å/5Å (Height cm)	10Å/5Å (Area)
PWS 81-4	12.7	3.3	40	9	3.8	4.4
PWS 81-5	10.8	3.3	32	9	3.3	3.6
PWS 81-6	10.5	2.3	32	10	4.6	3.2
PWS 81-7	13.3	3.5	42	8	3.8	5.3
PV 50	10.5	4.4	21	8	2.4	2.6
PV 56	8.5	2.6	14	6	3.3	2.3
PE 9	5.1	0.9	14	2	5.7	7.0
PE 13	5.6	1.0	19	3	5.6	6.3

APPENDIX G . Supported and excess ^{210}Pb values.

	Core Number	Supported ^{210}Pb (dpm/g)
Supported ^{210}Pb		
	PV 80-3	1.00
	PV 80-5	1.16
	PV 80-6	1.41
	PWS 82-40	1.00
	PWS 82-41	0.68
	PWS 82-43	0.73

	Core Number	Excess ^{210}Pb (dpm/g)	Core Depth (cm)
Excess ^{210}Pb			
	PV 80-3	4.00	0-1
		2.50	1-2
		2.50	2-3
		1.70	3-4
		0.70	4-5
		0.40	5-6
		0.40	6-7
		0.20	7-8
		0.10	8-9
		0.20	10-11
		0.10	12-13
		0.10	14-15
	PV 80-5	3.64	0-1
		3.54	1-2
		3.04	2-3
		2.44	3-4
		1.74	4-5
		1.84	5-6
		2.74	6-7
		2.24	7-8
		1.64	8-9
		1.24	9-10
		1.54	10-11
		1.54	12-13
		0.94	13-14
		1.04	14-15

APPENDIX G . continued.

	Core Number	Excess ^{210}Pb (dpm/g)	Core Depth (cm)
Excess ^{210}Pb (continued)	PV 80-6	3.49	0-1
		2.99	1-2
		3.19	2-3
		2.99	3-4
		2.59	4-5
		1.59	5-6
		1.59	6-7
		1.79	7-8
		1.59	9-10
		1.19	10-11
		2.29	12-13
		1.69	13-14
	PWS 82-40	6.20	0-1
		5.20	1-2
		5.80	2-3
		5.90	3-4
		4.80	4-5
		5.00	5-6
		4.40	6-7
		3.80	7-8
		3.50	8-9
		3.70	9-10
		3.50	10-11
		3.10	11-12
		3.70	12-13
	PWS 92-41	3.12	0-1
		3.22	1-2
		3.12	2-3
		2.92	3-4
		2.22	4-5
		2.02	5-6
		1.92	6-7
		2.22	7-8
		1.72	8-9
		1.52	9-10
		1.02	10-11
		1.12	11-12
		0.72	12-13
		0.62	13-14
		0.52	14-15

APPENDIX G . continued.

	Core Number	Excess ^{210}Pb (dpm/g)	Core Depth (cm)
Excess ^{210}Pb (continued)	PWS 82-43	2.17	0-1
		1.67	1-2
		1.97	2-3
		1.77	3-4
		1.67	4-5
		1.27	5-6
		0.77	6-7
		1.47	7-8
		0.97	8-9
		1.07	9-10
		0.67	10-11
		0.67	11-12

APPENDIX H . Water content of the gravity core sections used for ^{210}Pb dating in the central basin of Prince William Sound.

Core Number	Depth (cm)	Wet Weight (g)	Dry Weight (g)	% Water
PWS 82-40	0-1	51.271	17.670	65.54
	1-2	77.589	40.100	48.32
	2-3	39.232	21.110	46.19
	3-4	53.725	28.936	46.14
	4-5	60.383	35.509	41.19
	5-6	37.058	20.995	43.35
	6-7	49.232	27.864	43.40
	7-8	42.108	23.589	43.98
	8-9	45.312	25.255	44.26
	9-10	45.852	25.922	43.47
	10-11	44.069	24.917	43.46
	11-12	52.339	29.866	42.99
	12-13	52.472	30.042	42.75
	24-25	56.334	30.392	46.05
	39-40	54.617	30.636	43.91
	59-60	61.909	35.175	43.18
	79-80	59.170	33.899	42.71
	89-90	65.605	38.547	41.24
	99-100	56.475	33.433	40.80
	109-110	60.500	36.414	39.81
PWS 82-41	0-1	28.319	12.026	57.53
	1-2	26.194	12.466	52.41
	2-3	49.916	27.568	44.77
	3-4	43.399	24.237	44.15
	4-5	43.329	24.275	43.98
	5-6	39.136	21.973	43.85
	6-7	42.909	24.263	43.45
	7-8	50.151	27.784	44.60
	8-9	47.557	25.497	46.39
	9-10	48.741	26.429	45.78
	10-11	47.420	25.951	45.27
	11-12	51.965	27.682	46.73
	12-13	66.661	36.117	45.82
	13-14	70.940	39.124	44.85
	14-15	53.858	29.920	44.45
	24-25	66.240	40.100	39.46
	39-40	75.479	55.646	26.28
	59-60	63.598	48.988	22.97
	79-80	62.646	48.266	22.95

APPENDIX H . continued.

Core Number	Depth (cm)	Wet Weight (g)	Dry Weight (g)	% Water
PWS 82-43	0-1	67.304	30.607	54.52
	1-2	61.063	35.420	41.99
	2-3	41.891	25.712	38.62
	3-4	75.255	45.549	39.47
	4-5	53.469	32.014	40.13
	5-6	48.448	28.957	40.23
	6-7	50.103	29.547	41.03
	7-8	46.814	27.460	41.34
	8-9	64.420	38.660	39.99
	9-10	50.405	30.475	39.54
	10-11	42.703	25.752	39.70
	11-12	59.065	35.758	39.46
	17-18	52.006	32.028	38.41
	24-25	49.213	29.950	39.14
	39-40	42.775	27.853	34.88
	59-60	47.081	30.450	35.32
	79-80	52.005	34.115	34.40

APPENDIX I. Total concentrations of heavy metals in the surficial bottom sediments of Prince William Sound. All values are in μg/g except those of Fe whose concentrations are in μg/g × 10^4.

Sample Number	Zn	Co	Cr	Cu	Ni	V	Pb	Mn	Fe
PWS 66-20	105	53	98	40	70	300	5	850	4.00
PWS 66-21	93	43	60	33	55	273	5	700	4.00
PWS 66-22	58	30	50	28	35	140	15	500	2.00
PWS 66-23	100	53	88	33	66	300	15	1,000	4.00
PWS 79-1	213	19	100	360	33	175	35	627	4.33
PWS 79-2	103	20	100	45	43	240	20	685	4.63
PWS 79-3	110	23	100	50	43	290	30	725	3.98
PWS 79-4	108	20	60	45	33	175	13	510	3.98
PWS 79-5	108	19	105	53	37	260	20	725	4.80
PWS 79-6	98	19	110	50	40	285	13	785	5.13
PWS 79-7	103	23	105	53	45	250	20	845	5.25
PWS 79-8	115	23	105	50	45	283	25	900	5.25
PWS 79-9	130	29	110	50	47	295	25	1,020	5.63
PWS 79-10	115	26	110	50	47	283	20	940	5.50
PWS 79-11	205	15	105	55	47	284	30	900	5.50
PWS 79-12	200	26	110	60	47	283	25	880	5.50
PWS 79-13	120	23	105	38	45	183	35	900	5.25
PWS 79-14	115	26	110	35	47	283	35	900	5.50
PWS 79-15	115	25	110	28	45	283	25	1,040	5.38
PWS 79-16	115	26	105	28	47	283	25	940	5.50
PWS 79-17	110	29	112	55	50	293	25	980	5.85
PWS 79-18	115	25	118	45	47	273	25	860	5.25
PWS 79-19	103	20	102	30	43	263	25	960	5.25
PWS 79-20	115	20	121	38	47	230	30	845	4.80
PWS 79-21	103	19	107	25	43	195	30	785	4.23
PWS 79-22	115	23	118	50	47	260	35	920	5.13
PWS 79-23	85	14	81	25	27	175	25	590	3.25
PWS 79-24	103	20	89	50	33	210	13	685	4.23
PWS 79-25	110	27	110	55	47	273	30	1,080	5.68
PWS 79-26	95	19	95	38	37	230	25	685	4.75
PWS 79-27	110	23	105	35	41	260	20	1,080	5.38
PWS 79-28	100	21	89	48	35	209	25	845	4.60
PWS 79-29	110	25	105	53	44	250	25	1,080	5.25
PWS 79-30	103	22	98	48	44	240	30	940	4.88
PWS 80-1	552	26	128	77	45	161	18	990	4.94
PWS 80-2	824	31	143	84	47	178	18	1,530	5.02
PWS 80-3	792	35	144	42	49	178	18	1,965	4.94
PWS 80-4	112	33	153	52	49	178	13	810	4.22

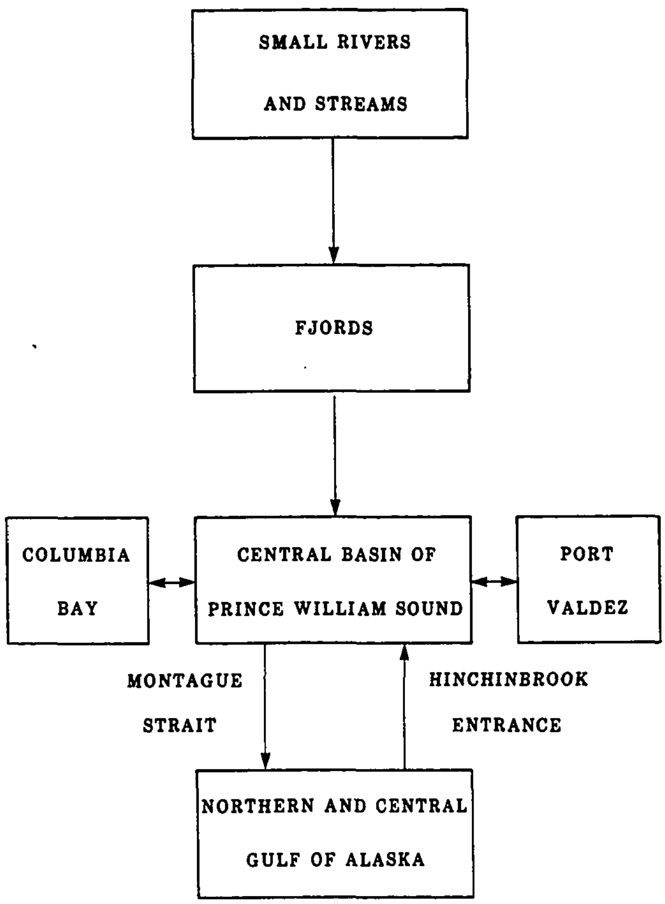
APPENDIX I. continued.

Sample Number	Zn	Co	Cr	Cu	Ni	V	Pb	Mn	Fe
PWS 80-5	98	31	132	40	46	161	13	1,005	4.52
PWS 80-6	112	28	132	52	40	161	13	885	4.48
PWS 80-7	112	30	135	102	45	166	13	780	4.52
PWS 80-8	112	24	146	55	47	166	13	825	4.64
PWS 80-9	128	24	128	95	43	178	20	870	4.86
PWS 80-10	80	19	121	90	41	161	15	750	4.56
PWS 80-12	120	28	128	67	47	184	20	930	4.86
PWS 80-13	104	21	108	52	34	161	20	735	4.18
PWS 80-14	80	19	93	30	24	132	20	720	3.50
PWS 80-15	128	30	132	67	47	195	23	960	5.24
PWS 80-16	112	26	128	62	45	184	20	900	5.09
PWS 80-17	112	30	130	70	47	184	20	945	5.05
PWS 80-18	80	14	66	23	23	86	13	330	2.70
PWS 80-19	304	24	130	47	49	166	20	1,020	4.79
PWS 80-20	128	31	130	72	45	189	20	915	5.09
PWS 80-21	112	30	153	70	53	184	20	900	4.83
PWS 80-22	112	28	114	105	38	161	20	690	4.33
PWS 80-23	96	18	143	77	32	149	20	600	3.08
PWS 80-24	112	10	89	30	16	109	30	495	2.66
PWS 80-25	128	11	157	87	45	161	30	735	3.80
PWS 82-1	103	68	88	50	66	188	20	1,300	4.00
PWS 82-2	93	28	70	43	50	248	15	575	3.25
PWS 82-3	95	45	85	40	56	263	25	600	3.00
PWS 82-4	95	50	78	48	56	263	18	950	3.25
PWS 82-5	105	50	50	40	60	175	8	575	2.00
PWS 82-7	95	50	73	65	56	248	18	875	3.50
PWS 82-8	110	53	90	48	66	288	20	750	3.50
PWS 82-9	150	68	88	83	70	300	20	1,175	4.25
PWS 82-10	133	75	105	75	75	300	23	1,000	4.50
PWS 82-12	123	63	60	48	70	288	20	1,100	4.00
PWS 82-13	118	43	80	40	56	250	15	700	3.25
PWS 82-14	245	60	85	48	56	250	18	1,175	3.25
PWS 82-15	103	53	85	70	60	250	25	875	3.50
PWS 82-16	58	38	68	28	41	175	25	500	2.00
PWS 82-17	135	70	98	75	53	288	23	950	4.50
PWS 82-18	68	38	73	28	50	225	8	925	2.50
PWS 82-19	103	45	73	40	60	225	10	875	3.50
PWS 82-20	75	38	73	48	53	200	18	1,050	3.00
PWS 82-21	88	50	80	28	56	238	15	1,100	4.00
PWS 82-22	68	48	73	28	56	225	8	700	3.50
PWS 82-23	93	58	78	38	60	175	15	2,400	4.00

APPENDIX I . continued.

Sample Number	Zn	Co	Cr	Cu	Ni	V	Pb	Mn	Fe
PWS 82-24	88	53	73	38	53	225	8	925	3.50
PWS 82-25	65	45	85	33	56	225	3	1,000	3.50
PWS 82-26	75	43	73	38	56	200	5	525	3.00
PWS 82-27	110	53	70	55	60	175	15	425	2.00
PWS 82-28	75	50	73	45	60	200	8	675	3.50
PWS 82-29	80	48	85	48	56	225	8	675	3.50
PWS 82-30	78	48	85	88	56	275	20	625	3.50
PWS 82-31	105	50	73	38	45	250	8	625	2.50
PWS 82-32	75	50	85	55	56	275	30	625	4.00
PWS 82-33	75	58	85	55	63	263	17	700	4.00
PWS 82-34	75	50	85	50	60	225	25	575	4.00
PWS 82-35	80	48	78	33	53	250	8	700	3.25
PWS 82-36	75	53	73	42	56	250	10	700	3.75
PWS 82-37	78	38	40	33	40	153	30	525	2.00
Mean	123	34	100	52	47	217	19	828	4.00

APPENDIX J. Box model showing the major arteries of suspended sediment transport responsible for the accumulation of sediments in Prince William Sound.



APPENDIX K. Concentrations of heavy metals in the total sediments, hydroxylamine hydrochloride-acetic acid extracts, and the percentages of various metals extractable from the total sediments of Chenega-Knight Island area, Prince William Sound.

Sample Number	Zinc			Copper			Cobalt			Nickel			Chromium			Vanadium			Manganese			Iron		
	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E
PWS 82-2	93	30	32	43	14	33	28	6	22	50	8	16	70	2	3	248	5	2	575	87	15	32,500	3,390	10
PWS 82-5	105	27	25	40	16	39	50	9	18	60	6	11	50	3	5	175	15	9	575	400	70	20,000	3,290	17
PWS 82-7	95	21	22	65	13	19	50	6	12	56	5	10	73	2	2	248	8	3	875	230	26	35,000	2,470	7
PWS 82-9	150	24	16	83	17	20	68	9	13	70	7	10	88	2	2	300	16	5	1,175	440	37	42,500	3,620	9
PWS 82-12	123	24	19	48	18	36	63	10	15	70	6	8	60	2	4	288	18	6	1,100	510	46	40,000	3,360	8
PWS 82-13	118	34	28	40	20	50	43	8	19	56	9	15	80	3	3	250	10	4	700	230	33	32,500	3,780	12
PWS 82-14	245	12	47	48	18	36	60	6	11	56	5	8	80	1	2	250	6	2	1,175	515	44	32,500	1,510	5
PWS 82-17	135	24	17	75	21	44	70	9	13	73	8	10	98	3	3	288	15	5	950	175	18	45,000	2,430	5
PWS 82-20	75	21	28	48	17	35	38	9	23	53	8	15	73	3	4	200	14	7	1,050	770	73	30,000	2,760	9
PWS 82-21	88	14	16	28	17	59	50	8	15	56	5	9	80	2	2	238	8	3	1,100	465	47	40,000	1,200	5
PWS 82-23	93	21	22	38	14	37	58	15	26	60	10	16	78	2	3	175	11	6	2,400	2,250	94	40,000	2,760	7
PWS 82-26	75	16	21	33	15	44	43	7	17	56	5	10	85	2	2	225	10	4	1,000	280	28	35,000	2,020	6
PWS 82-31	105	7	6	38	5	12	50	2	4	45	2	4	73	1	1	250	3	1	625	105	17	15,000	1,120	4
PWS 82-33	75	24	32	55	11	19	58	7	12	63	6	10	85	3	4	263	11	7	700	70	10	40,000	2,300	[illegible]
PWS 82-37	78	8	10	33	6	18	38	6	15	40	5	11	40	2	4	153	7	4	525	140	27	20,000	890	[illegible]

APPENDIX L. Concentrations of heavy metals in the total sediments, hydroxylamine hydrochloride-acetic acid extracts, and the percentages of the various metals extractable from the total sediments of Port Valdez, Prince William Sound.

Sample Number	Zinc			Cobalt			Chromium			Copper			Nickel			Vanadium			Lead[1]			Manganese			Iron		
	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E	T	E	%E
PV 11	127	20	16	27	9	33	140	3	2	75	28	37	58	13	22	220	4	2	--	11	--	1,195	140	12	5,630	2,900	52
PV 21	110	21	19	63	9	14	113	3	3	95	32	34	75	12	15	300	5	2	20	11	55	925	245	26	3,500	3,260	93
PV 25	133	27	20	26	10	38	142	2	1	68	26	38	52	11	21	213	8	4	--	12	--	1,175	165	14	5,600	3,360	60
PV 32	171	23	13	31	10	32	168	3	2	85	33	39	68	12	18	280	5	2	--	11	--	2,000	280	14	7,380	3,500	47
PV 33	161	75	47	25	8	32	142	3	2	120	25	21	57	9	16	220	8	4	--	13	--	980	60	6	5,300	3,620	68
PV 37	133	27	20	25	11	44	137	3	2	80	29	36	55	11	20	220	7	3	--	11	--	900	410	46	5,630	3,610	64
PV 39	115	21	18	68	10	15	113	2	2	84	28	33	78	10	13	300	4	1	20	12	60	975	330	34	3,500	3,420	98
PV 40	136	30	22	27	14	52	137	4	3	63	29	46	58	12	21	237	11	5	--	13	--	1,725	1,110	64	5,750	4,850	84
PV 41	88	34	39	58	17	29	113	4	4	70	33	47	73	13	18	300	15	5	18	13	72	3,150	2,600	83	4,500	3,460	77
PV 50	110	27	25	68	11	16	113	3	3	65	25	38	80	11	14	300	10	3	18	13	72	1,200	550	46	4,000	3,720	93
PV 57	117	29	25	25	11	44	142	3	2	63	28	44	55	11	20	213	6	3	--	12	--	1,200	490	41	5,500	3,550	65
PV 59	91	38	42	19	6	32	127	3	2	50	25	50	49	9	18	170	4	2	--	11	--	810	65	8	4,400	3,600	82
PV 73 (D-69)	136	49	36	22	8	36	137	4	3	60	33	55	52	9	17	213	8	4	--	11	--	980	87	9	5,130	3,450	67
PV 77	127	30	24	26	10	38	142	4	3	70	31	44	57	12	21	213	4	2	--	11	--	1,570	520	33	5,750	4,200	73

[1]Dashes (--) signify no data.

APPENDIX M. Average heavy metal concentrations of surficial bottom sediments in Prince William Sound and Port Valdez, Alaska. Values are in μg/g, except for Fe which is in μg/g × 10^4.

TOTAL CONCENTRATIONS

Metal	Prince William Sound	Port Valdez
Zn	123	125
Co	34	36
Cr	100	133
Cu	52	75
Ni	47	62
V	217	243
Pb	19	19
Mn	828	1,342
Fe	4.00	5.00

CONCENTRATIONS OF EXTRACTABLE METALS

Metal	Chenega-Knight Island Area	Port Valdez
Zn	20	32
Co	8	10
Cr	2	3
Cu	14	29
Ni	6	11
V	10	7
Pb	12	12
Mn	506	504
Fe	2.42	3.75

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